#58

PICOAMMETER MODEL 930A

INSTRUCTION MANUAL

MP MASTER
MA29079

EG&G
Laboratory Products Division

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1. DESCRIPTION AND SPECIFICATIONS

1.1 GENERAL

The EG&G Model 930A Digital Picoammeter is a solid state instrument capable of automatically measuring positive or negative direct current from 20 milliamps to 10 femptoamps (10^{-14} amps). The digital readout consists of seven neon glow tubes arranged left to right on the front panel to display polarity, amperes mantissa, and range multiplier exponent, respectively. The measured current is displayed to three significant digits plus a fourth overrange digit.

Only one digital output is provided as standard on the model 930A -- that for remote polarity monitoring/ recording. Optional outputs are available for digital recording of amperes and range multiplier. These options are described in Section 6.

Figure 1.1 EG&G Picoammeter, Model 930A.

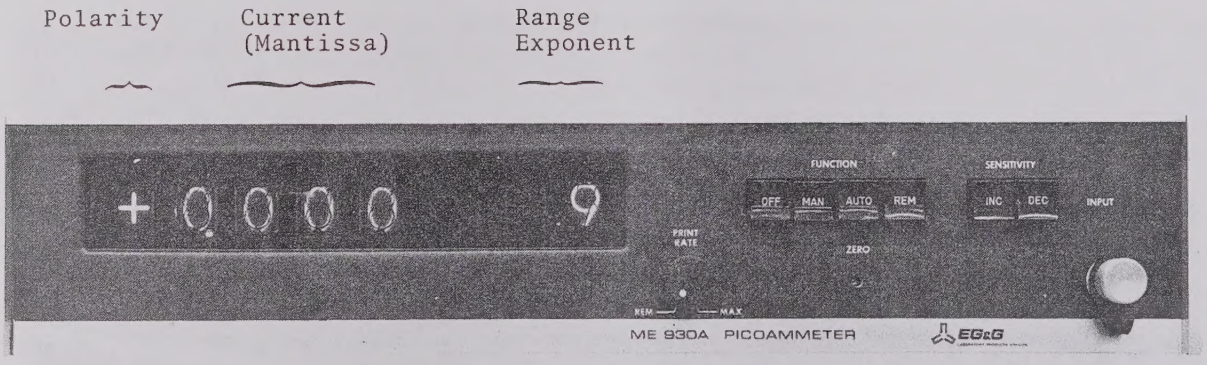


Figure 1.2 Picoammeter 930A -- Front Panel.

1.2 CONTROLS AND ACCESSORIES

1.2.1 Front Panel

The following are located on the front panel of the 930A Picoammeter as shown in Figure 1.2:

POLARITY DISPLAY	Automatically indicates polarity of the input current.
CURRENT (MANTISSA) DISPLAY	Indicates the digital value of current in amperes from 0.001 to 1.999 times the decade range multiplier.
RANGE EXPONENT DISPLAY	Number indicated is the negative exponent of the decade range multiplier, e.g., 9 in this position would be read 10^{-9}.
OFF	Turns the instrument power off. Depressing any of the function switches, except OFF, turns instrument power on.
MAN	Places the instrument in the manual range changing mode of operation.
AUTO	Places the instrument in the automatic range changing mode of operation.
REM	Enables remote programming of all front panel pushbutton functions except OFF and ZERO.
INC	Increases the sensitivity of the instrument one decade for each depression of the pushbutton.
DEC	Decreases the sensitivity of the instrument one decade for each depression of the pushbutton.
ZERO	Fine adjustment for input voltage offset.
INPUT	Input connector with BNC shielding cap.

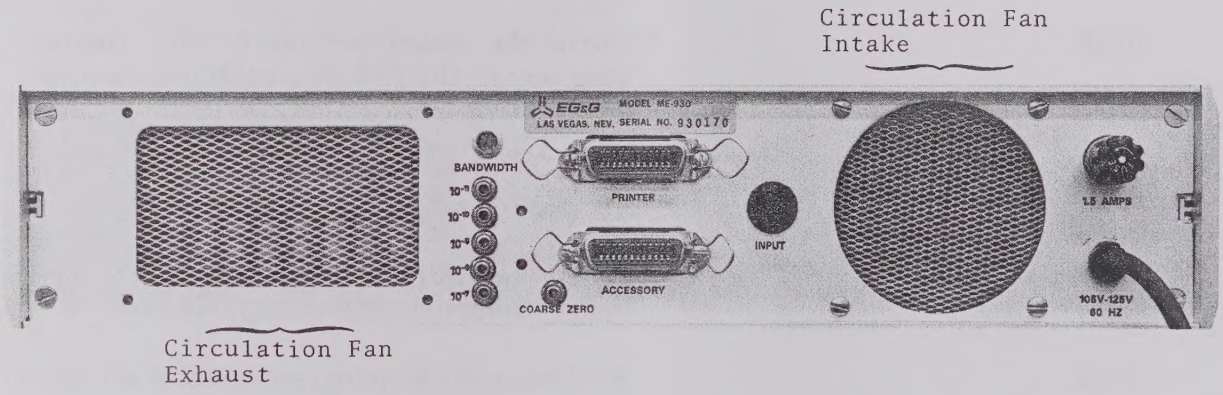


Figure 1.3 Picoammeter 930A -- Rear Panel.

1.2.2 Rear Panel

The following are located on the rear panel of the 930A Picoammeter as shown in Figure 1.3:

CIRCULATION FAN EXHAUST	DO NOT RESTRICT AIR FLOW.
BANDWIDTH	Bandwidth control for varying response and noise rejection. Maximum bandwidth is full CW.
-11	10^{-11}
-10	10^{-10}
-9	10^{-9}
-8	10^{-8}
-7	10^{-7}

Range calibration potentiometers

COARSE ZERO	Coarse adjustment for input voltage offset (not included in 930A serial numbers 930184 and above).
PRINTER	Connector for digital outputs.
ACCESSORY	Connector for analog outputs, remote control, power for EG&G model 601 A Pico-Calibrator, and other accessories.
INPUT	Optional rear input connector with BNC shield cap.
CIRCULATION FAN INTAKE	DO NOT RESTRICT AIR FLOW.
FUSE	1.5 amp, 250-volt, type 3 AG, slow-blow.
POWER CORD	105/125-volt, 50/60-Hz, three-wire.

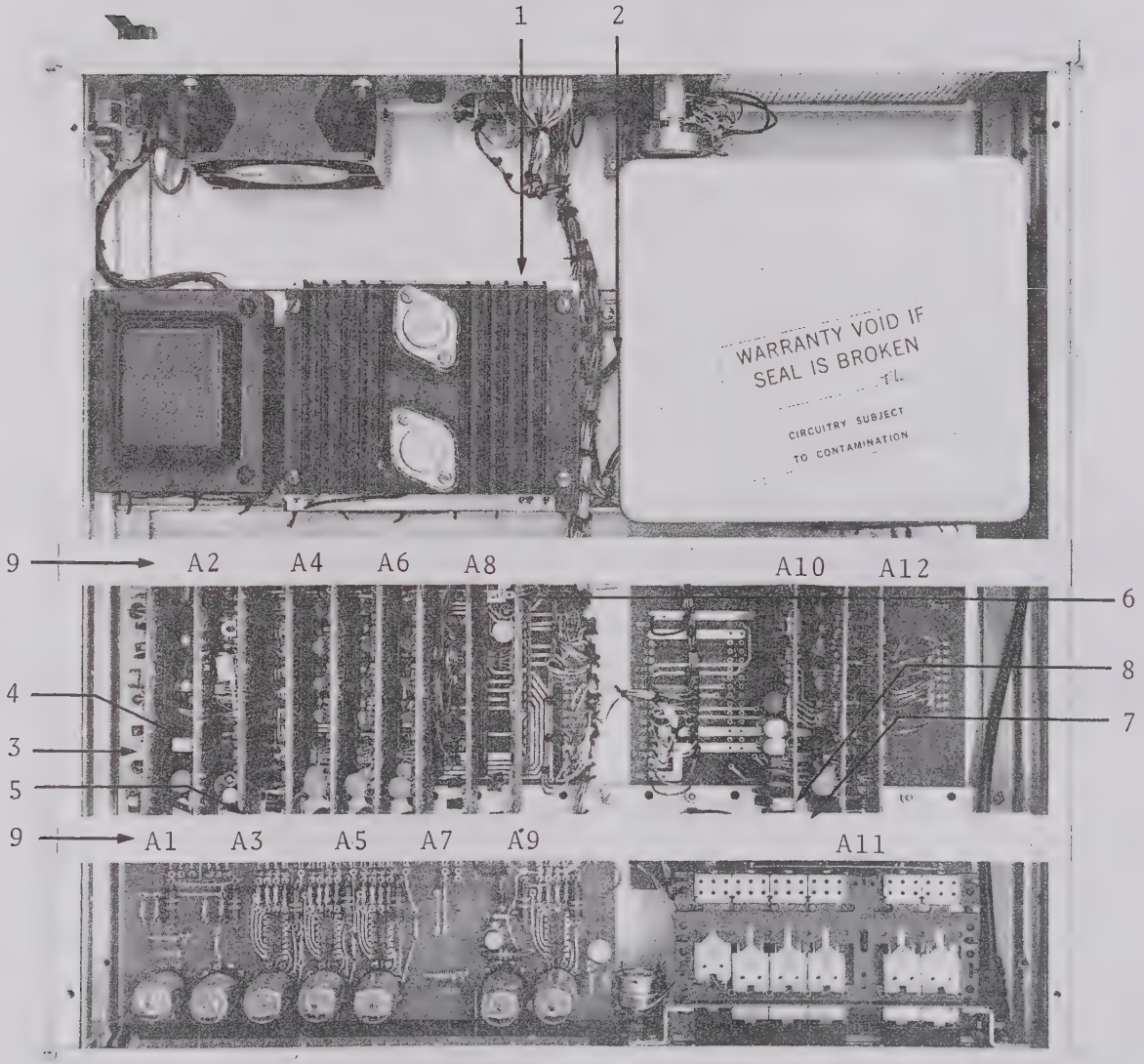


Figure 1.4 Picoammeter 930A -- Chassis, Top View.

1.2.3 Interior Chassis

The following are located as shown in Figure 1.3.

1 -- ± 15-volt power supply adjustments.

2 -- ± 15-volt power supply terminals.

3 -- Absolute value zero adjustment.

4 -- A-to-D converter full scale adjustment.

5 -- A-to-D converter zero adjustment.

6 -- Slow/Fast print rate switch (installed on digital output options only).

7 -- Automatic range increase adjustment.

8 -- Automatic range decrease adjustment.

9 -- Printed circuit boards, A1 through A12:

A1 - Absolute value.

A2 - Analog-to-digital converter amplifier.

A3 - Analog-to-digital control.

A4 - Digital-to-analog converter -- 13 bit.

A5 - Forward-reverse decimal counting unit.

A6 - Forward-reverse decimal counting unit.

A7 - Forward-reverse decimal counting unit.

A8 - Optional.

A9 - Optional.

A10 - Range control.

A11 - Forward-reverse decimal counting unit.

A12 - Decoder driver.

1.3 SPECIFICATIONS

Details of the 930A specifications are shown in Table 1.1.

1.3.1 Range

Full scale ranges are in ten inclusive decade steps from 10^{-2} amperes to 10^{-11} amperes. One hundred percent overranging on all ranges allows a maximum current display of ± 1.999 (multiplied by the range factor).

Range changing is either automatic or manual, selected at the front of the panel or remotely programmed. Manual range changing is accomplished by momentary-contact, front panel pushbuttons labeled INC and DEC, i.e., increase and decrease sensitivity. Each depression of the appropriate pushbutton changes the full scale sensitivity by one decade. Automatic range changing requires use of the AUTO pushbutton, only. In the AUTO mode, the clock rate is 15 ms per range, and the sensitivity threshold levels are:

	Nominal	Adjustment Span
Sensitivity increase threshold	17.5%	20% - 12% f.s.
Sensitivity decrease threshold	195%	200% - 185% f.s.

1.3.2 Polarity

Positive input current is defined as conventional current into the center conductor of the BNC input connector. Polarity determination and display are automatic. A digital output is provided for remote polarity monitoring.

1.3.3 Accuracy

Accuracy is specified as the maximum error accumulated when calibration is according to the procedure in this manual, and is valid at 25° C, ±1°C, 0-50% relative humidity, 105/125 VAC, 60 Hz (±5 Hz) for one month after calibration. Accuracy figures in Table 1.1 do not consider the effects of input voltage offset or input current offset.

1.3.4 Input Characteristics

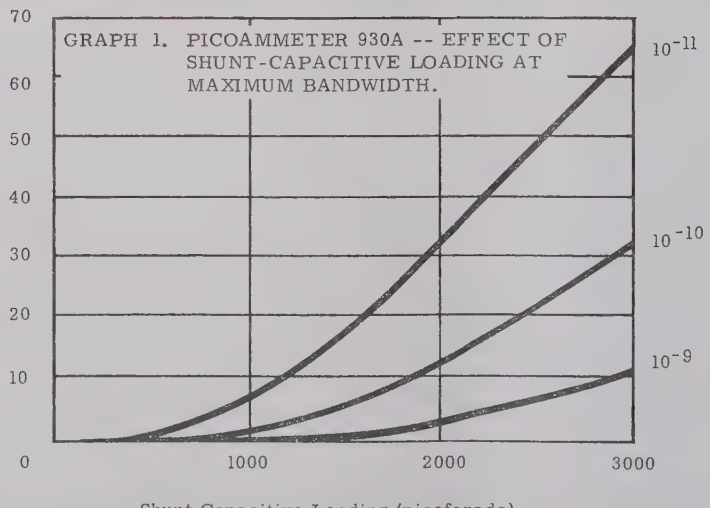
Voltage Offset:

1) Temperature coefficient ±150μv/° C, 5° C to 50° C.

RANGE	ACCURACY[1] (±% of read ±% of f.s.)	MAX. INPUT	INPUT RESIST (Ω)	INPUT VOLT. DROP[2]	TEMP COEFF (ppm/°C)	BANDWIDT EFFECT OF B/W CONTROL ON NORMAL MODE NOISE REJECTION AT 60 Hz (db)		
						MIN B/W Fully CCW	50% B/W Mid-Point	MA
10^{-2}	±.05 ±.1	220 ma	.1	1 mv	± 100	33	33	33
10^{-3}	±.05 ±.1	220 ma	.1	100µv	± 100	33	33	33
10^{-4}	±.05 ±.1	220 ma	.1	10µv	± 100	33	33	33
10^{-5}	±.05 ±.1	220 ma	.5	5µv	± 100	33	33	33
10^{-6}	±.05 ±.1	220 ma	5	5µv	± 100	33	33	33
10^{-7}	±.15 ±.1	500 v	50	5µv	± 300	33	33	33
10^{-8}	±.25 ±.1	500 v	500	5µv	±1000	48	42	33
10^{-9}	±.35 ±.1	500 v	5K	5µv	±1000	66	60	38
10^{-10}	±.45 ±.1	500 v	50K	5µv	±1000	85	80	48
10^{-11}	±.55 ±.1	500 v	500K	5µv	±1000	105	100	66
10^{-12}	± 1.55							
10^{-13}	± 10							
10^{-14}	± 100							

Since the last full-scale range (10^{-11}) has three-digit resolution, stated accuracies can be realized for these inputs.

Display Uncertainty (± counts)



GRAPH 1. PICOAMMETER 930A -- EFFECT OF SHUNT-CAPACITIVE LOADING AT MAXIMUM BANDWIDTH.

N

1. Conditions requred for spec ±1° C; relative humidity, 0- 60 Hz, ±5 Hz. Effects of in
2. Input voltage drop for full s
3. Values in these columns are are not appreciably affected 3,000 picofarads.

CONTROL CHARACTERISTICS AND RESPONSE TIMES WITH STEP INPUT

ANALOG OUTPUT RESPONSE					DIGITAL OUTPUT RESPONSE		
Bandwidth (Hz)	Time Constant 0-63%	Rise Time 10 - 90%			Time for Digital Display To Reach .2% of Full Value		
2.5K [3]	60µs [3]	180µs	180µs	180µs [3]	100 ms	100 ms	100 ms [3]
2.5K	60µs	180µs	180µs	180µs	100 ms	100 ms	100 ms
2.5K	60µs	180µs	180µs	180µs	100 ms	100 ms	100 ms
2.5K	60µs	180µs	180µs	180µs	100 ms	100 ms	100 ms
2 K	80µs	700µs	180µs	180µs	100 ms	100 ms	100 ms
850	270µs	4ms	1.8ms	400µs	100 ms	100 ms	100 ms
390	400µs	35ms	16ms	900µs	142 ms	110 ms	100 ms
40	3ms	300ms	140ms	10ms	850 ms	400 ms	103 ms
10	15ms	2.5s	1.2s	32ms	6.8 s	3.4 s	136 ms
1.3	120ms	25s	12s	270ms	68 s	33 s	750 ms
IMUM BANDWIDTH Fully Clockwise		MIN B/W Fully CCW	50% B/W Mid-Point	MAX B/W Fully CW	MIN B/W Fully CCW	50% B/W Mid-Point	MAX B/W Fully CW

BANDWIDTH CONTROL SETTINGS

OTES
fied accuracy : temperature 25° C
0%; line voltage, 105/125 VAC,
ut offsets have not been considered.

ale indication on respective range.

obtained at maximum bandwidth and
by capacitance input loading up to

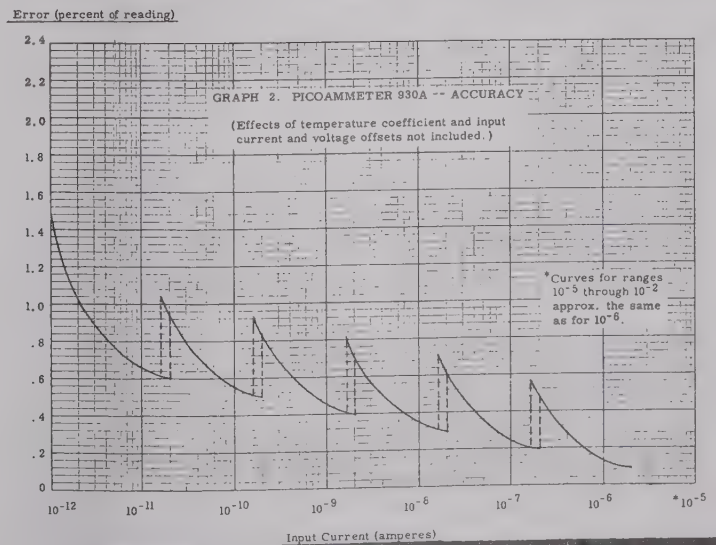


Table 1.1 Picoammeter 930A Specifications.

2) Drift	< 3mv in one week, after one hour warm-up.
3) Adjustment	To within 50μv of zero.

An offset of 5 mv results in 1 count of instrument offset on ranges 10^{-2} through 10^{-10}, and 5 counts on the 10^{-11} range.

Current Offset:

1) Temperature coefficient	$\pm 5 \times 10^{-15}$ amp/°C, 5°C to 35°C.
2) Steady state	10^{-13} amp maximum, 5×10^{-14} amp typical.

Input Resistance:

The maximum input resistance and corresponding voltage drop for full scale input current are given in Table 1.1.

Isolation:

The BNC input connector to the 930A is isolated from the chassis and power line with approximately 1200 pf in parallel with 1000 megohms. A maximum difference in potential of ±150v or 115v RMS, 60 Hz can be sustained between the input connector and chassis with no change in specifications.

1.3.5 Noise

Self-generated noise is less than $\pm 2 \times 10^{-14}$ amperes as observed on the digital display with the BANDWIDTH control set at maximum (fully CW).

The total digital display uncertainty will increase for increased shunt input capacitance loading. Refer to Graph 1 at the bottom of Table 1.1 for the approximate predicted noise level for the maximum BANDWIDTH control setting. With the control set at minimum (fully CCW), noise will be reduced to less than ±1 count for 3000 pf of loading on all ranges.

1.3.6 Outputs

Analog Output:

1) Bipolar analog	+5v, f.s., 2 ma maximum, ±10v @ 100% overrange. Polarity opposite to input.

2) Monopolar analog	0 to +5v f.s., 1ma maximum, (0 to +10 v @ 100% overrange). Positive polarity independent of input.

Digital Output:

1) Polarity	Single-line binary, positive zone, diode-coupled. Negative polarity: > + 6v, 3.3K. Positive polarity: < + 1v, 2ma sink, maximum.

The digital output options are described in Section 6.

1.3.7 Remote Programming

Remote programming is single point control, i.e., each programmed function is controlled by a single program line. Remote programming is functional only when the REM pushbutton is depressed.

Operations that are remotely controlled:

1) Automatic range changing

2) Manual range changing

3) Manual sensitivity increase

4) Manual sensitivity decrease

When activated, the remote control operation requires a switch closure between the control line and remote common line or a saturated NPN transistor. In the inactive state, the remote control operation requires an open circuit between the control line and remote common line or a cutoff NPN transistor.

2. PREPARATION FOR USE

2.1 GENERAL

This instrument was inspected both mechanically and electrically before shipment. The instrument should be in operating condition upon receipt, however, the top cover should be removed and the instrument inspected for damage before applying power. The following items are packaged with the instrument:

1) Instruction manual.

2) Mating connectors (Amphenol #57-30240) for ACCESSORY and PRINTER outputs.

If necessary to repackage the instrument for shipment, place it in the original container. If a substitute container is used, package as follows:

1) Wrap instrument in heavy paper or plastic before placing in an inner container.

2) Use sufficient packing materials around all sides of instrument and protect panels faces with cardboard strips.

3) Place instrument and inner container in a heavy carton or wooden box and seal with strong tape or metal bands.

4) Mark shipping container "DELICATE INSTRUMENT - FRAGILE".

Accompanying the instruments should be information identifying the owner and indicating the service or repair to be accomplished. Include the model number and full serial number of the instrument.

SHIP TO: EG&G, INC.
Laboratory Products Division
P.O. Box 755
Goleta, California 93017

2.2 INSTALLATION

2.2.1 Mechanical

The 930A Picoammeter can be rack mounted or operated as a bench-top unit. Rack mounting adapters are available from EG&G (address as in Section 2.1). Access for mounting the rack adapters is accomplished by snapping of the rear end caps and sliding the handle cover plate off (refer to Figures 2.1 and 2.2). The rack mount ears replace the rear end caps.

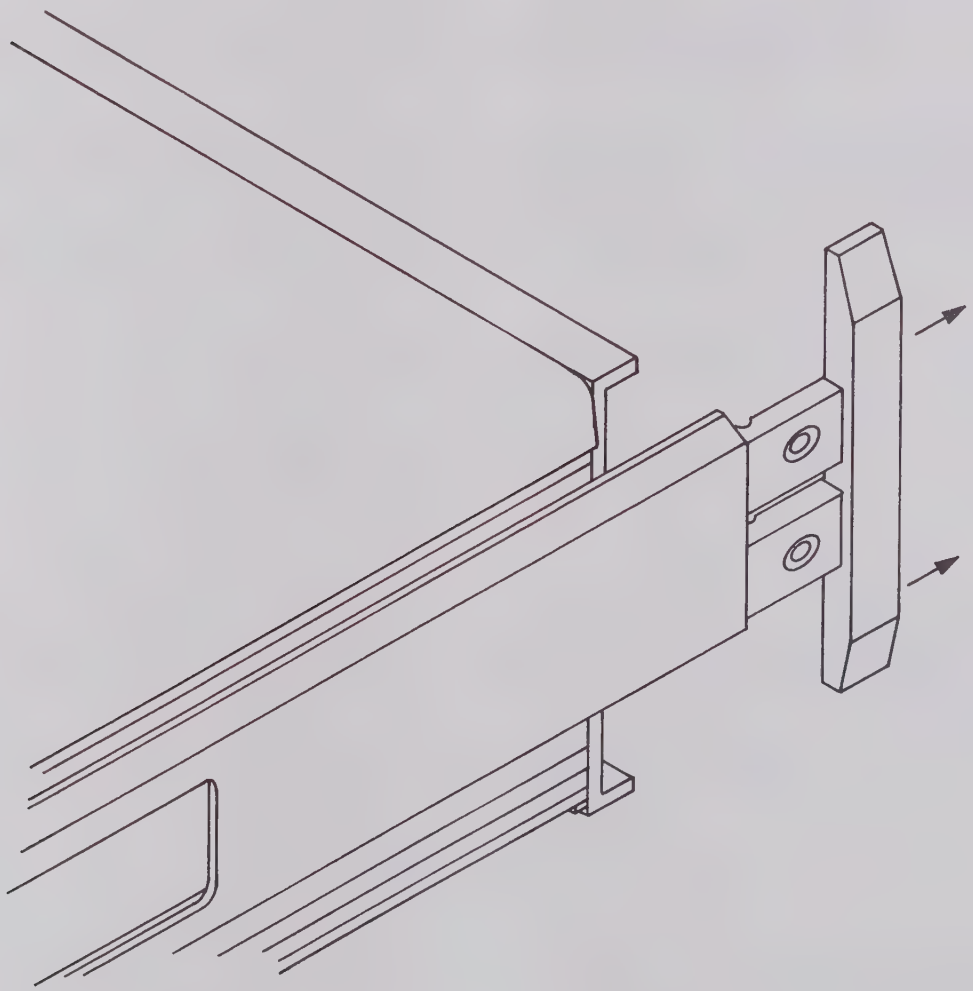


Figure 2.1 Rear End Cap.

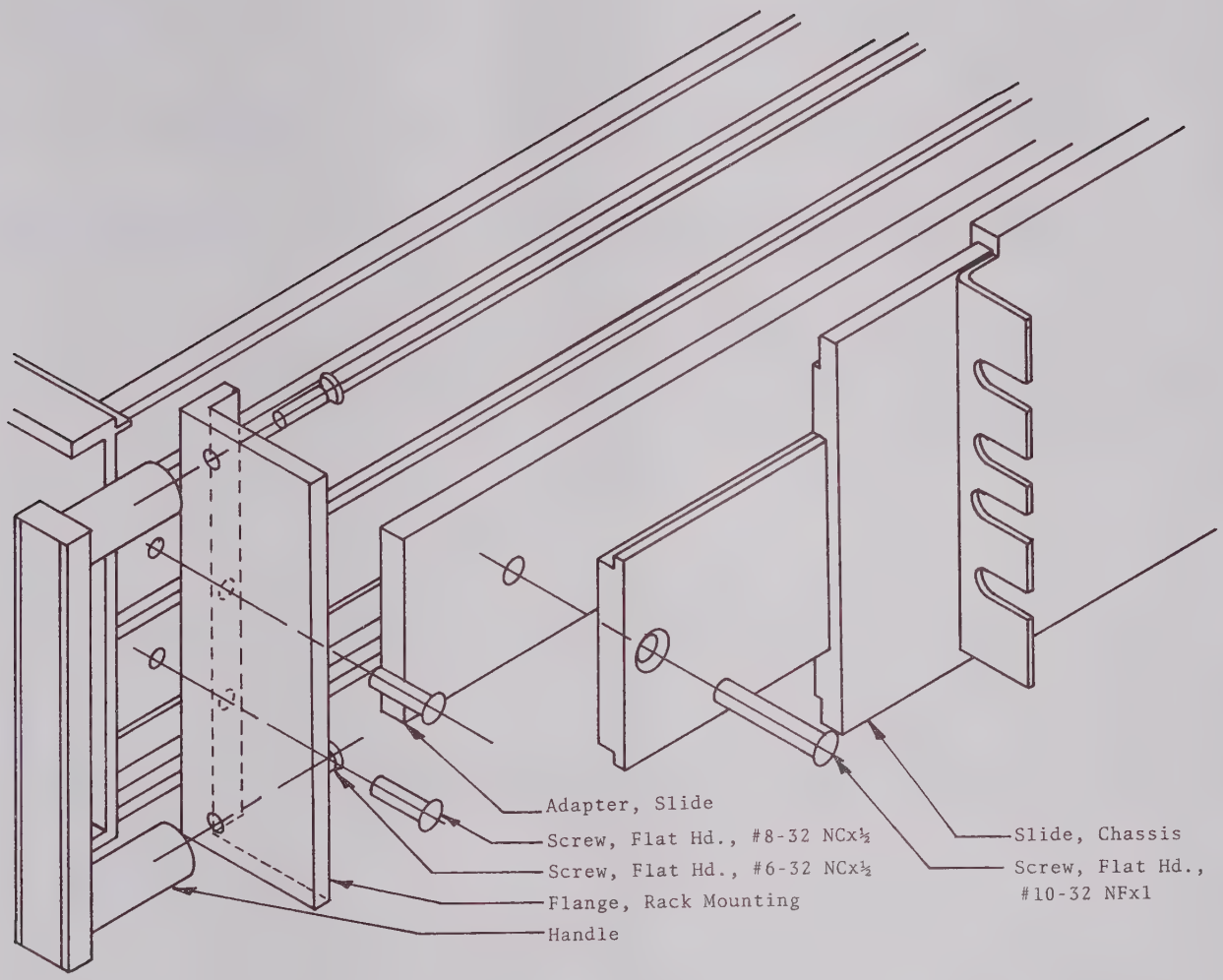


Figure 2.2 Rack Handle and Slide Assembly.

IMPORTANT

On the most sensitive ranges, effects of mechanical vibration and input cable movement will generate noise currents which may cause undesirable jitter in the digital display, or in extreme cases, automatic range changing uncertainty. Care should be taken to minimize flexing of input cable and all types of vibration.

(The use of low noise cable, such as Amphenol #21-537, will reduce the effects of cable flexing.)

2.2.2 Electrical

Power requirements for the 930A Picoammeter are 105/125-volt, 50/60-Hz, three-wire service.

The input connector is a coaxial BNC type. Recommended hookup cable is Amphenol #21-537 with a teflon insulated BNC connector.

To fully utilize the complete range of sensitivity, all connectors, test fixtures, photomultipliers, systems, etc. must be shielded as shown in Figure 2.3 to eleminate or reduce the effects of power line radiation and/or physical movement of people or equipment.

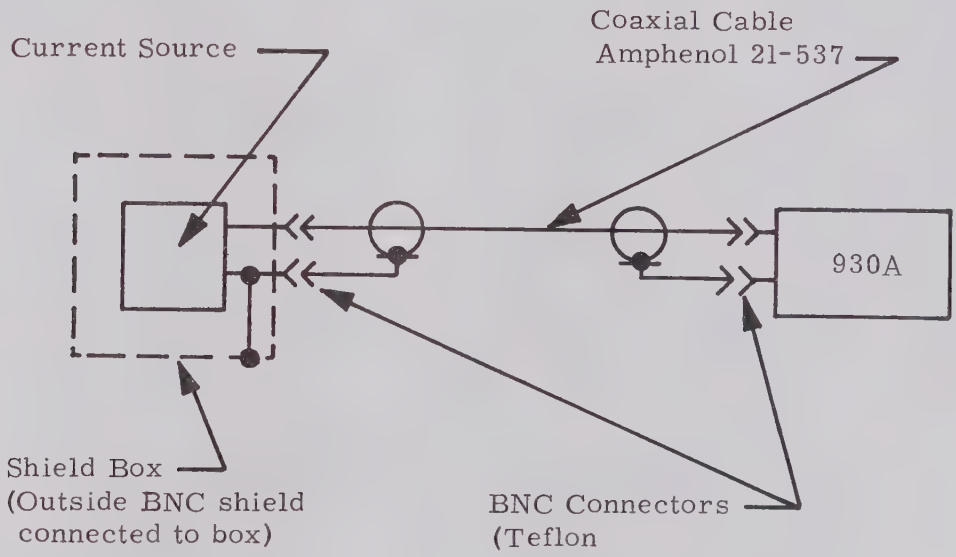


Figure 2.3 Input Shielding Requirements.

Input/output connections are provided via the rear panel ACCESSORY and PRINTER microribbon connectors. Table 2.1 lists the connections for the standard Model 930A. Connections for optional input/output configurations can be found in Section 6.

Table 2.1 Pin designations for the ACCESSORY and PRINTER connectors.

ACCESSORY Connector (J-3)

Pin	Designation
1	remote manual decrease
2	remote manual increase
3	remote manual
4	remote program common
6	bipolar analog ±5v full scale, ±10v overrange
7	monopolar analog 0 to +5v f.s. 0 to 10v o.r.
8	analog common
	internal power supply
22	+15v
23	-15v
24	common

PRINTER Connector (J-4)

Pin	Designation
5	common
7	polarity (+ = < 1v - = > 6v)
(all other pins blank)	

(Note: Polarity logic levels shown at pin 7 above are for the standard version of the 930A. Polarity logic levels for the options will differ as specified in Section 6.)

The configuration for remote control is shown in Figure 2.4. Programming is single point control to a remote common wire provided at the ACCESSORY connector, J-3. The .1μf capacitors may be deleted when solid state switching is used.

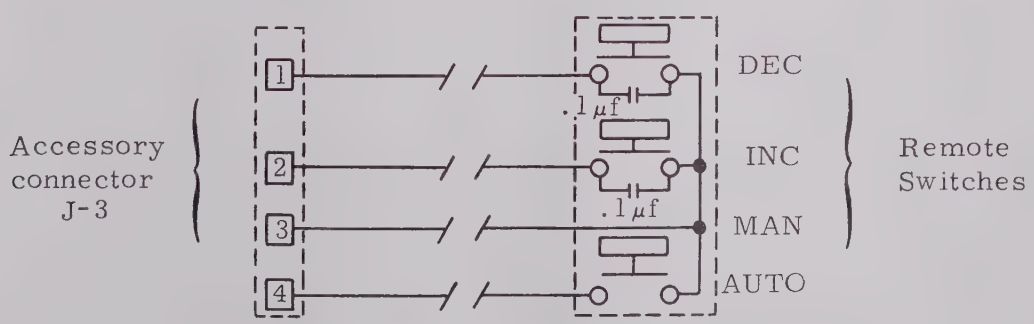


Figure 2.4 Remote Control Connections.

3. OPERATING INSTRUCTIONS

3.1 TURN-ON AND ZEROING

1) Connect the 930A to a grounded (three-wire), 105/125-volt, 50/60-Hz source.

2) Depress the AUTO pushbutton and allow the instrument to warm up for 10 minutes.

3) Place the shield cap on the input connector.

4) Adjust the front panel ZERO control for an indicated 0.000 amperes and polarity crossover. This will result in an input voltage offset of 3mv or less.

The instrument is now ready for use.

3.1.1 Close Zeroing

This procedure should be used prior to calibrating the 930A or when equivalent source voltages might affect the accuracy of the measurement (see Section 4.2).

1) Connect the instrument to a power source as in 3.1, step 1.

2) Allow 1 hour for warm-up.

3) Depress the MAN pushbutton.

4) Depress the DEC pushbutton successively until the range exponent display indicates 2.

5) Short circuit the BNC input center conductor and shield. The resulting display on the 930A will consist of the input offset voltage multiplied by the input amplifier open loop gain. (The display will probably indicate an overloaded condition.)

6) Center the ZERO control between polarity crossover. This procedure will allow adjustment of the input offset to less than 100μv.

3.2 CURRENT MEASUREMENT

3.2.1 Manual Mode

1) Perform Section 3.1 (or Section 3.1.1, if applicable).

2) Depress the MAN pushbutton.

3) Depress the DEC pushbutton successively until the range exponent indicates 2.

4) Connect the current source to be measured to the 930A INPUT with coaxial cable and teflon insulated BNC connectors as prescribed in Section 2.2.2.

5) Successively depress the INC pushbutton until the display indicates between 0.200 and 1.999.

6) The polarity and magnitude of input current may now be read.

3.2.2 Automatic Mode

1) Perform Section 3.1 (or Section 3.1.1, if applicable); Depress AUTO.

2) Connect the current source to be measured to the 930A INPUT as in Section 3.2.1, step 4.

3) The polarity and magnitude of input current may now be read.

3.3 BANDWIDTH CONTROL ADJUSTMENT/NOISE LEVEL

(Refer to Section 1.3.5 for discussion of 930A noise characteristics.)

1) Turn the bandwidth (BW) control fully CCW (min. BW, max. noise damping).

2) Perform Section 3.2.1.

3) Turn the BW control fully CW (max. BW, min. noise damping).

4) Advance the BW control CCW until the observed noise is acceptable.

3.4 REMOTE OPERATION

1) Complete the electrical connections required for remote operation (refer to Figure 2.4).

2) Perform Section 3.1 (or Section 3.1.1 if close zeroing is desired).

3) Depress REM pushbutton.

4) Perform 3.2.1 or 3.2.2 as required.

4. THEORY OF OPERATION

4.1 MEASUREMENT OF LOW-LEVEL, DIRECT-COUPLED CURRENT

The measurement of direct-coupled current to sensitivities less than 1 picoampere has generally been accomplished by two methods: The Shunt (Electrometer) Method and the Operational Method.

4.1.1 Analysis of the Shunt Method

The Shunt Method utilizes a high voltage input resitance voltmeter (electrometer) in measuring the voltage drop across a high value resistor. The circuitry is shown in Figure 4.1.

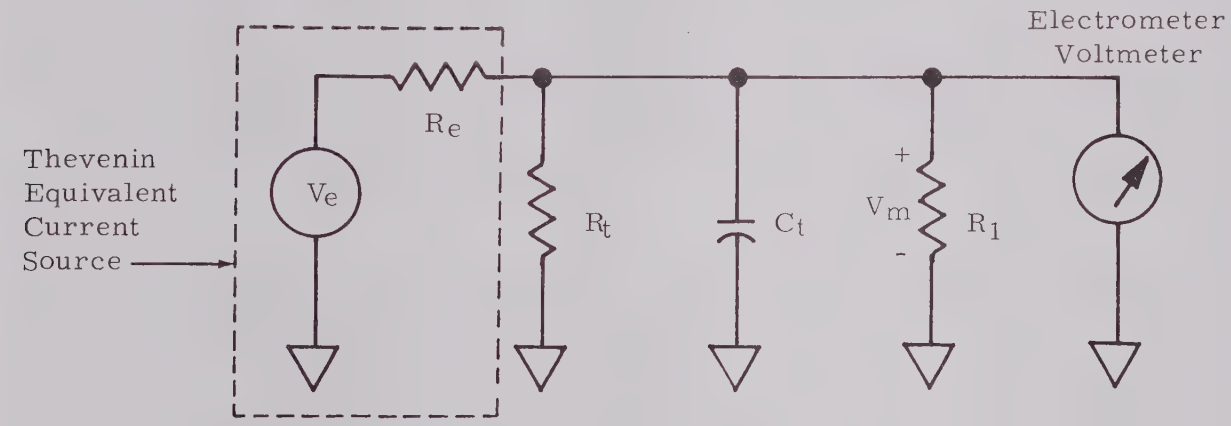


Figure 4.1 Circuitry for Shunt Method of Measuring Low-Level, Direct-Coupled Current.

Where V_e is the Thevenin equivalent source voltage,

R_e is the Thevenin equivalent source resistance,

R_1 is the shunt dropping resistance,

R_t is the total leakage resistance (cable, electrometer, and connectors),

V_m is the voltage drop measured by the electrometer, and

C_t is the total stray capacitance of cable, source, etc.

Solving for V_m,

$$V_m = \frac{V_e}{R_e} \quad R_1 \quad \left(\frac{1}{1 + \frac{R_1}{R_e} + \frac{R_1}{R_t}} \right). \qquad (1)$$

Two inequalities may be applied to this expression, $R_t >> R_1$ (effect of shunt leakage with respect to the dropping resistor is negligible), and $R_e >> R_1$ (circuit loading is negligible*).

The application of these inequalities simplifies the general expression and reveals the effects of leakage and loading. When $R_t >> R_1$, $R_e >> R_1$,

$$V_m \simeq \frac{V_e}{R_e} \quad R_1 \left[1 - \left(\frac{R_1}{R_e} + \frac{R_1}{R_t} \right) \right]. \qquad (2)$$

The term in brackets may be interpreted as an error term consisting of contributions by leakage $\frac{R_1}{R_t}$ and loading $\frac{R_1}{R_e}$.

For example, suppose

$V_e = 1$ volt,

$R_e = 10^{12}$ ohms,

$R_1 = 10^{10}$ ohms,

$R_t = 5 \times 10^{13}$ ohms, and

$V_m = .01 (1 - .01 - .002)$ volts $= .988 \times 10^{-2}$.

The error contributed by leakage and loading is -1.2%.

The effects of electrometer offset and the inaccuracy of R_1 becomes immediately ately evident: Offset of 1 mv causes a .1% error, and the inaccuracy of R_1 is directly related to an equal inaccuracy at the voltmeter input.

In addition, the large value of input resistance (10^{10} Ω) has a serious effect on bandwidth, e.g., 100 pf of C_t will cause a 2.35 second, 10 - 90% response to a step input.

* The dual of a voltage measurement where it is desirable to maintain $R_1 >> R_e$.

4.1.2 Analysis of the Operational Method

The Operational Method utilizes a low leakage operational amplifier with resistance feedback. The basic circuit is shown in Figure 4.2.

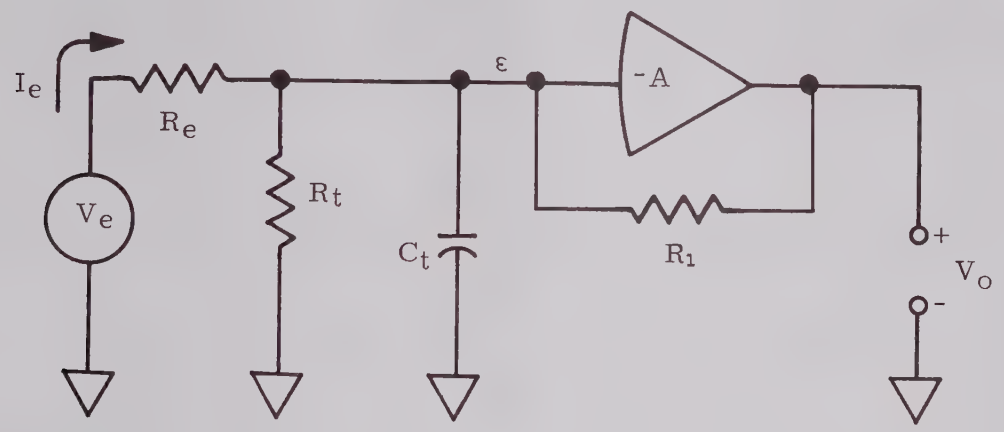


Figure 4.2 Circuitry for Operational Method of Measuring Low-Level, Direct-Coupled Current.

Where V_e, R_e, R_t, and C_t have the same definition as in the Shunt analysis, and

R_1 is the voltage dropping resistor now inserted in the feedback of an operational amplifier,

-A is the open loop gain of the amplifier,

ε is the summing junction voltage*, and

V_o is the amplifier output voltage.

The DC node equation at the summing junction is

$$\varepsilon(G_e + G_t + G_1) - V_e G_e - V_o G_1 = 0; \tag{3}$$

also,

$$V_o = -A\varepsilon. \tag{4}$$

Combining and rearranging produces

$$-V_o = V_e \frac{R_1}{R_e} \left[\frac{1}{1 + \frac{1}{A}\left(1 + \frac{R_1}{R_e} + \frac{R_1}{R_t}\right)} \right]. \tag{5}$$

* ε is not offset, but is the actual input voltage required to produce an output.

For $A \gg 1$,

$$-V_o \simeq V_e \frac{R_1}{R_e}\left[1 - \frac{1}{A}\left(1 + \frac{R_1}{R_e} + \frac{R_1}{R_t}\right)\right]. \qquad (6)$$

Note that the error term is similar to that obtained for the shunt method, except that the effects are reduced by the open loop gain of the operational amplifier. In fact, if the inequalities are satisfied, the error term approaches simply

$$\left(1 - \frac{1}{A}\right).$$

Applying the same circuit parameters as in the shunt example,

$V_e = 1$ volt,

$R_e = 10^{12}$ ohms,

$R_1 = 10^{10}$ ohms,

$R_t = 5 \times 10^{13}$ ohms, and

$A = 20,000$,

and solving for V_o, we have

$$-V_o = .01\left[1 - \left(\frac{.01 + .002 + 1}{20,000}\right)\right] = .9999494. \qquad (7)$$

Thus, in the same application, the operational method has reduced the error from 1.2% to less than .01%. Amplifier offset* and the precision of R_1 contribute to error as in the shunt example.

The inaccuracy of R_1 may be adjusted with a potentiometer in the feedback loop as shown in Figure 4.3.

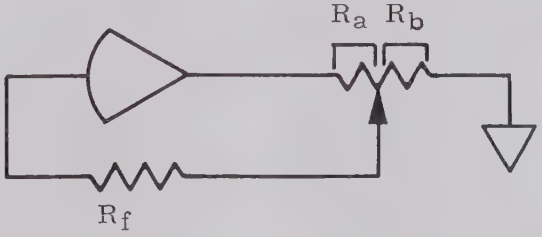


Figure 4.3 Variable Feedback Loop.

*Refer to Section 4.2.

Now the effective feedback resistor becomes

$$R_1 \text{ (effective)} = R_f \left(\frac{R_a}{R_b} + 1 \right) + R_a . \tag{8}$$

Thus, the variations in large value resistors may be easily adjusted by the ratio of $R_a : R_b$.

4.1.3 Input Resistance

Referring to Figure 4.2, the Norton equivalent source current is

$$I_e = V_e G_e . \tag{9}$$

Also,
$$R_{in} = \frac{\epsilon}{I_e} \quad \text{(assuming the leakage is negligible).} \tag{10}$$

Rearranging equation (3)

$$\epsilon = \frac{V_e G_e}{G_e + G_t + G_1 + AG_1} \; ; \tag{11}$$

and for $A >> 1$

$$R_{in} \simeq \frac{R_1}{A} \left[1 - \frac{1}{A} \left(\frac{R_1}{R_e} + \frac{R_1}{R_t} \right) \right] . \tag{12}$$

For all pratical purposes,

$$R_{in} \simeq \frac{R_1}{A} \; . \tag{13}$$

Again, a reduction by the open loop gain.
For a 2.35-second, 10 - 90% riset ime as in the shunt case, the value of C_t would have to be increased by 20,000 to 2μf.

4.1.4 Advantages of the Operational Method

All circuit parameters being equal, the obvious improvements realized by the Operational Method of current measurement over the Shunt Method are:

1) Lower input resistance:

a) Reduction in source loading.

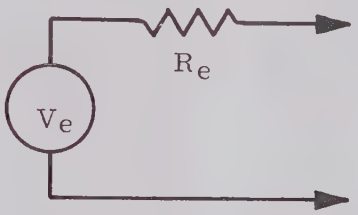
b) Faster response time.

c) Less emphasis need be placed on extremely high leakage resistance at the input amplifier.

2) Low current measuring instruments may be easily calibrated for variation in large value resistors.

4.2 ERROR EFFECT OF INPUT VOLTAGE OFFSET AND SOURCE RESISTANCE

A source of current may be reduced to the equivalent



where V_e and R_e are the familiar Thevenin equivalent voltage and resistance. This circuit in turn may be connected to an operational type current-to-voltage converter such as in Figure 4.4;

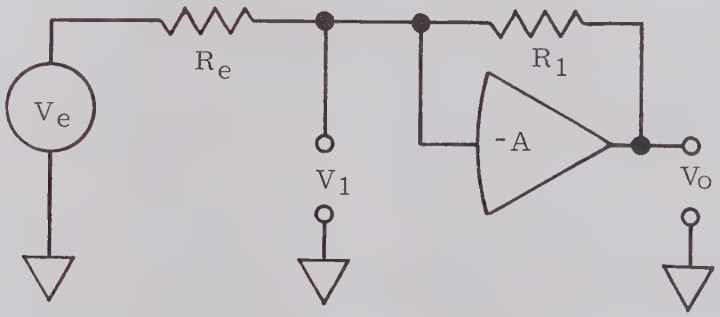


Figure 4.4 Operational Type Current-to-Voltage Converter.

where A is the open loop gain (assumed to approach ∞ for this example),

R_1 is the feedback (transfer function) resistor,

V_1 is the fixed summing junction offset voltage, and

V_o is the amplifier output voltage.

Writing the node equation at the summing junction, we have

$$V_1 (G_e + G_1) - V_e G_e - V_o G_1 = 0 \tag{14}$$

or,

$$V_1 \left(\frac{1}{R_e} + \frac{1}{R_1}\right) - V_e \left(\frac{1}{R_e}\right) - V_o \left(\frac{1}{R_1}\right) = 0. \tag{15}$$

Solving for V_o,

$$-V_o = \frac{V_e}{R_e} R_1 - V_1 \left(\frac{R_1}{R_e} + 1\right) \tag{16}$$

The first term in equation (16) is the desired output, the second term is an error contributed by V_1 .

If we define

$$\frac{V_e}{R_e} R_1 \triangleq V_{ot} \text{ (true output)}, \tag{17}$$

then the % error contributed by V_1 is

$$\% \text{ error} = \left(\frac{V_1}{V_e} + \frac{V_1}{V_{ot}}\right) \times 100. \tag{18}$$

The error due to summing junction offset is minimized by (1) keeping the ratio of offset to equivalent source voltage small, and (2) keeping the ratio of offset to full scale output small.

The second term would be evident with no input source by an output equal to V_1. The first term usually predominates in most applications.

In practice, the close zeroing procedure of the 930A reduces error attributable to the second term to less than .002% full scale. At the same time, the source voltage would have to be less than 100 mv to result in an error of .1% because of the first term.

4.3 INPUT AND RANGE CHANGING CIRCUITRY

Figure 4.5 is a block diagram of the input and range changing circuits.

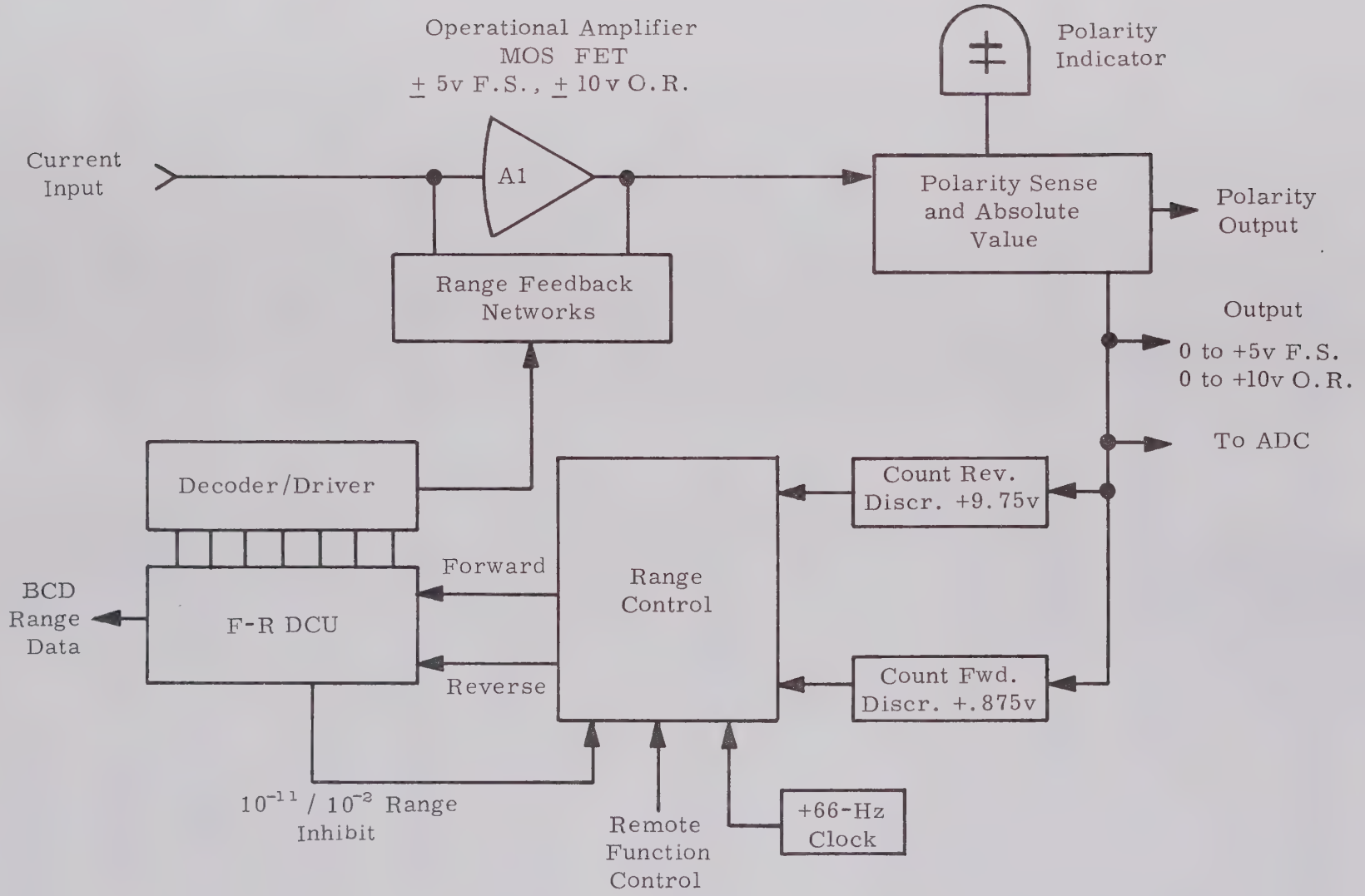


Figure 4.5 Input and Range Changing Circuits -- Block Diagram.

4.3.1 Input Amplifier

The 930A input amplifier consists of a high gain, insulated-gate, field-effect transistor (IGFET) operational amplifier with the range changing feedback resistors switched by reed relays. Such an arrangement is shown in Figure 4.6.

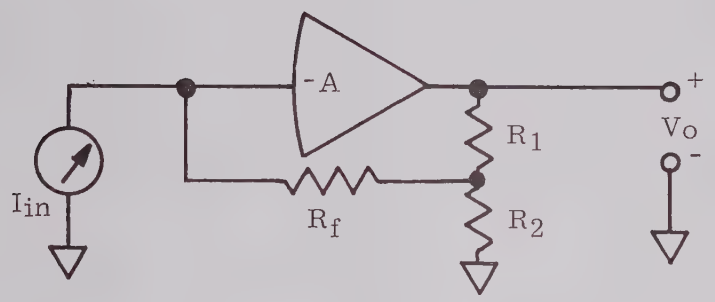


Figure 4.6 Operational Amplifier with Variable Resistive Feedback.

This type of amplifier will exhibit the transfer function

$$Z_{21} = \frac{-V_o}{I_n} = R_f\left(\frac{R_1}{R_2} + 1\right) + R_1 ,$$

providing the open loop gain is infinite, and the input offset voltage and current are zero.

In a pratical circuit these three conditions are never met; consequently, the degree to which they are approached dictates the performance of this type of current-to-voltage converter. Calibration of the input amplifier is accomplished by adjusting the ratio of R_1 to R_2. Since replacement of high megohm resistors is eliminated, periodic calibration may be performed in a more straight forward manner. The full-scale output of the IGFET amplifier (A1) in Figure 4.6 is +5v to -5v for negative and positive full-scale inputs, respectively (±10v for 100% overrange).

4.3.2 Polarity and Absolute Value

The output voltage from the IGFET input amplifier is connected to a polarity sensing and absolute value circuit. The polarity sensing circuit inserts an inverting amplifier in series with the output for negative output voltage and passes the voltage straight through for positive output. Thus, the bipolar analog signal at the output of A1 is converted to a positive unipolar analog signal at the absolute value output. The polarity sensing circuit also lights the correct polarity sign on the front panel indicator.

4.3.3 Automatic Range Changing

Any given state (0 through 9) of the forward-reverse decimal counting unit (F-R DCU) will result in a discrete combination of feedback elements to be connected to A1 via the decoder-driver and reed relays. State "0" is equivalent to 10^{-2} amps F.S., state "1", 10^{-3} amps, etc. to state "9", 10^{-11} amps. One pulse applied to the forward input of the F-R DCU will increase its state to the next increment, (e.g. "8" to "9") and one pulse applied to the reverse input will decrease its state one increment.

The output of the absolute value is applied to two adjustable discriminators, one set at +.875 volts (17.5% f.s.) and one at +9.75 volts (195% f.s.). Absolute value output in excess of 9.75 volts will allow the 66-Hz clock to be applied to the reverse input of the F-R DCU, thus decreasing A1 sensitivity. The pulses will be applied as long as the absolute value output is in excess of +9.75 volts, or until the DCU reaches "0", equivalent to maximum full-scale input range of 10^{-2} amps. An output less than +.875 volts will cause pulses to count the DCU forward until the sensitivity is increased sufficiently to cause greater than 17.5% full-scale input on a given range, or until the DCU reaches "9", equivalent to the most sensitive range of 10^{-11} amps. Outputs from the DCU are used to inhibit automatic or manual range changing below "0" or above "9".

In the manual mode, each depression of the INC or DEC pushbuttons will allow one pulse to be applied to the forward or reverse inputs of the DCU, respectively, thus increasing or decreasing the range sensitivity by one decade.

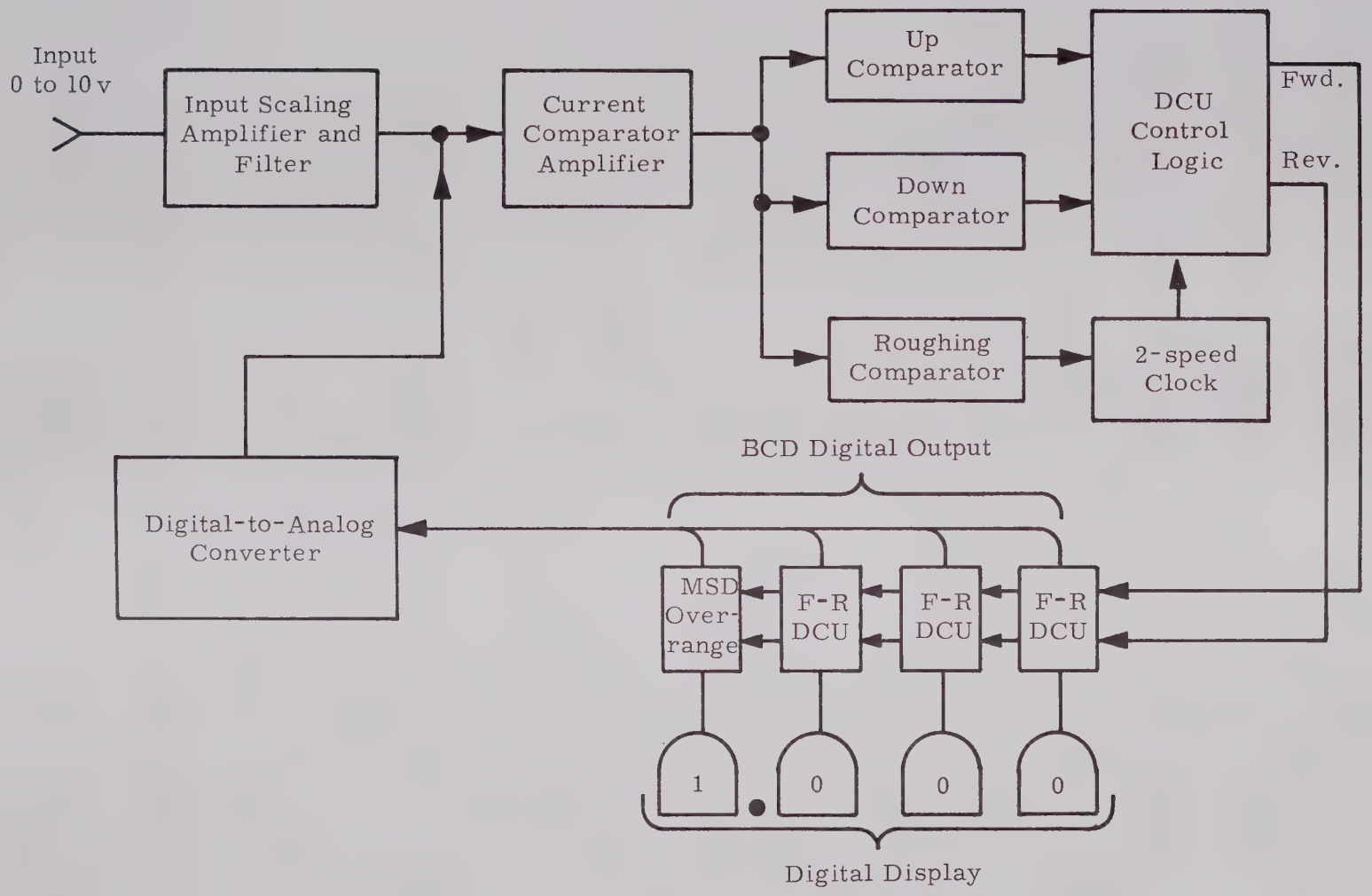


Figure 4.7 Analog-to-Digital Converter -- Block Diagram.

Because of range overlap in the automatic mode, a value of current between 175% and 195% of full scale on a given range might possibly be displayed on the next less sensitive range.

4.4 ANALOG-TO-DIGITAL CONVERTER (ADC) (Refer to Figure 4.7)

The input to the ADC is derived from the absolute value output, scaled at 0 to +5 volts full scale. Full-scale ADC display is 1.000 with provision for 100% overrange to 1.999. Inputs to the 930A in excess of 1.999 (overload) will cause the ADC to fall out of null, resulting in a blur of digits. Each display digit is controlled by a F-R DCU. BCD outputs from each F-R DCU are connected to a digital-to-analog converter (DAC). The DAC output current is scaled at approximately .45μa per least significant digit (LSD), the maximum DAC output being approximately 900μa. The DAC current is continuously compared with the varying analog input and the amplified difference between the two signals is fed to the current comparator. The current comparator voltage output is then matched against the four fixed voltage levels shown in Figure 4.8.

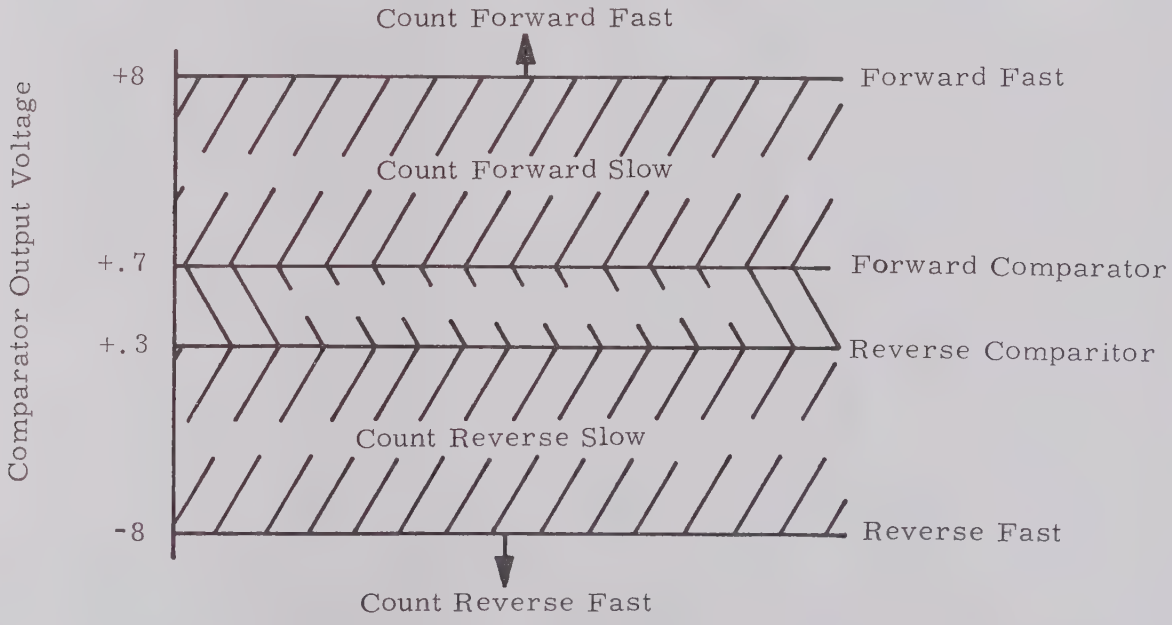


Figure 4.8 Decimal Counting Unit -- Comparator Control Logic Levels.

Depending on the voltage level at the comparator output, the DCU control logic will cause the DCU's to count forward fast, forward slow, reverse fast, reverse slow, or stop when a null is reached. The combination of high and low-speed nulling is accomplished in less than 25 ms. The actual conversion time is slowed down to approximately 60 ms by a three-pole, Butterworth-Thompson filter on the ADC input to provide normal mode noise rejection.

5. CALIBRATION

5.1 PRE-CALIBRATION ADJUSTMENTS

5.1.1 Test Equipment Required

Power Supply -- Short term stability ±.02% or better for 20 volts, adjustable output @ 200μa.

Digital Voltmeter -- Accuracy ±.02% or better.

Resistor -- 100K, ±5%.

5.1.2 Power Supply Adjustment

Power supply accesses and adjustments for the 930A are shown in Figure 1.4. Tolerance on ±15-volt supplies is ±30 ms. (On newer versions of the 930A, adjustment requires removal of card retainer plate.) The ±185-volt power supply tolerance is ±15 volts with no adjustment provided.

5.1.3 Absolute Value Zero Adjustment

1) Connect the external power supply and the 930A as shown in Figure 5.1.

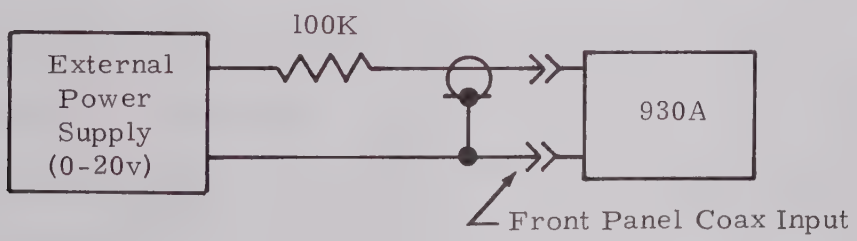


Figure 5.1 Equipment Connections for Absolute Value Zero Adjustment.

2) Remove the 930A top cover.

3) Connect the 930A to a 105/125-volt, 50/60-Hz, three-wire outlet.

4) Depress the AUTO pushbutton, and allow 10 minutes for warm-up.

5) Connect the DVM common to pin 8 on the rear panel ACCESSORY connector.

6) Apply the power to the expernal power supply and set the output at +10 volts.

7) Connect the DVM input to pin 6 on the ACCESSORY connector. Record the reading.

8) Connect the DVM input to pin 7 on the ACCESSORY connector.

9) Adjust the absolute value zero potentiometer for the same DVM indication (±1 mv) as in step 7. Note that the polarity is negative in step 7 and positive in steps 8 and 9.

5.1.4 ADC Calibration

1) Perform Section 5.1.3, steps 1 through 4.

2) Connect the DVM to pin 7 on the ACCESSORY connector.

3) Depress the MAN pushbutton, step 930A range to 4.

4) Adjust the external power supply to indicate +10v, ±1 mv, on the DVM (approximately 20 mv on the power supply).

5) Adjust the ADC zero pot to indicate precisely 0.002 on the 930A display.

6) Adjust the external power supply to indicate +9.975 volts, ±1 mv, on the DVM (approximately 20 mv on the power supply).

7) Adjust the ADC full-scale pot to indicate precisely 1.995 on the 930A display.

8) Recheck steps 4 through 7.

5.1.5 Automatic Range Changing Threshold Adjustment

1) Perform Section 5.1.3, steps 1 through 4.

2) Turn the AUTO decrease pot fully CW.

3) Turn the AUTO increase pot fully CCW.

4) Adjust the external power supply to indicate +0.175 4 on the digital display.

5) Turn the AUTO increase pot CW until the 930A range changes to range 5.

6) Adjust the external power supply to indicate +1.950 5 on the digital display.

7) Turn the AUTO decrease pot CCW until the 930A range changes to 4.

5.2 RANGE CALIBRATION

5.2.1 General

Refer to Section 5.2.4 for a discussion of the Bootstrap technique used to calibrate the 10^{-7} through 10^{-11} ranges.

During the range calibration procedure, noise may cause flickering in the 930A display. The bandwidth control should be truned fully CW (facing rear panel of 930A) and then slowly CCW until the noise is reduced to an acceptable level.

5.2.2 Procedure for Calibrating Ranges 10^{-7} through 10^{-11}

The test equipment required:

Pico Calibrator -- EG&G Model TF-601A.

Digital Voltmeter -- Accuracy .02% or better.

1) Perform 3.1.2 (turn-on and close zeroing).

2) Depress INC successively, stepping 930A range to 6.

3) Connect micro-ribbon connector of 601A to rear panel ACCESSORY connector on 930A.

4) Connect a two-foot section of Amphenol #21-537 coaxial cable with teflon BNC connectors between the 601A current output (J1) and the 930A input.

5) Apply power to the 601A and set its controls as follows:

CURRENT	+
RANGE	10^{-7}
MULTIPLIER	10
VARIABLE	Adjust to indicate +1.700* 6 on 930A digital display.

6) Switch 601A MULTIPLIER to 1.

7) Depress AUTO pushbutton on 930A.

8) Adjust 10^{-7} pot on rear panel of 930A to indicate +1.700 7, $\pm$1 count, on digital display.

10^{-7} Calibration

9) Switch 601A RANGE to 10^{-8}.

10) Switch 601A MULTIPLIER to 10.

11) Adjust 601A VARIABLE to indicate +1.700 7 on 930A digital display.

12) Switch 601A MULTIPLIER to 1.

13) Adjust 10^{-8} pot on rear panel of 930A to indicate +1.700 8, $\pm$2 counts, on 930A digital display.

10^{-8} Calibration

14) Switch 601A RANGE to 10^{-9}.

15) Switch 601A MULTIPLIER to 10.

16) Adjust 601A VARIABLE to indicate +1.700 8 on digital display.

17) Switch 601A MULTIPLIER to 1.

18) Adjust 10^{-9} pot on rear panel to indicate +1.700 9, $\pm$3 counts, on digital display.

10^{-9} Calibration

19) Switch 601A RANGE to 10^{-10}.

20) Switch 601A MULTIPLIER to 10.

10^{-10} Calibration

* The maximum output of the 601A varies on each range. The value 1.700 is slightly below the least maximum value attainable.

21) Adjust 601A VARIABLE to indicate +1.700 9 on digital display.

22) Switch 601A MULTI PLIER to 1.

23) Adjust 10^{-10} pot on rear panel to indicate +1.700 10, ±4 counts, on digital display.

10^{-10} Calibration (cont'd.)

24) Switch 601A RANGE to 10^{-11}.

25) Switch 601A MULTIPLIER to 10.

26) Adjust 601A VARIABLE to indicate +1.700 10 on digital display.

27) Switch 601A MULTIPLIER to 1.

28) After approximately 30 seconds, adjust the 10^{-11} pot on the 930A rear panel to indicate +1.700 11, ±5 counts on digital display.

10^{-11} Calibration

29) Recheck display zero on the 930A and adjust if necessary.

30) Repeat steps 5 through 28 until the desired results can be obtained without adjusting the range potentiometers.

This completes calibration of the 10^{-7} through 10^{-11} ranges.

5.2.3 Procedure for Checking Accuracy of Ranges 10^{-6} through 10^{-2}

This section is to be performed only after Section 5.2.2 has been completed.

Test equipment required:

Precision Power Supply -- Cohu 324A

Resistor in Pomona Box -- 1M, ±.01%

Resistor in Pomona Box -- 100K, ±.01%

Resistor in Pomona Box -- 10K, ±.01%

Resistor in Pomona Box -- 1K, ±.01%

1) Perform Sections 3.1 and 3.1.1 (urn-on and close zeroing).

2) Depress MAN pushbutton on 930A and step 930A range to 6.

3) Set Cohu 324A controls as follows:

POWER -- ON
RANGE -- ZERO
DIALS -- 1 0 0 0 0 0

4) Using coax with teflon BNC connectors, connect pomona box with 1M resistor between Cohu 324A output and 930A input.

5) Switch Cohu 324A range to 10.

6) 930A display should read +1.000 6, ±1 count. If reading is not within ±1 count, repeat section 5.2.2.

7) Step 930A range to 5.

8) Change resistor to 100K.

9) 930A display should read +1.000 5, ±1 count. If reading is not within ±1 count, repeat section 5.2.2.

10) Step 930A range to 4.

11) Change resistor to 10K.

12) 930A display should read +1.000 4, ±1 count. If reading is not within ±1 count , repeat section 5.2.2.

13) Step 930A range to 3.

14) Change resistor to 1K.

15) 930A display should read +1.000 3, ±1 count. If reading is not within ±1 count, repeat section 5.2.2.

16) Step 930A range to 2.

17) Set Cohu 324A range to 100.

18) 930A display should read +1.000 2, ±1 count. If reading is not within ±1 count, repeat section 5.2.2.

This completes the accuracy check of ranges 10^{-6} through 10^{-2}. Unless otherwise necessary, this check need only be made on a quarterly basis.

5.2.4 Discussion of Bootstrap Calibration Technique

Bootstrap calibration is dependent upon the accurate division of current, not the accurate generation of current. The general procedure is to:

1) measure an unknown current with a precision wire-wound resistor,

2) divide that current by the factor of sensitivity increase to the next range, and

3) use the divided current to adjust the next most sensitive range.

Each successive bootstrap step uses the previously calibrated range to measure a new unknown current until all ranges are calibrated. Because bootstrap calibration does not depend upon the long term stability of high megohm resistors, it eliminates the weak link in the resistive calibration of picoammeters. However, bootstrap calibration is subject to the following inaccuracies:

1) Precision of the initial current measurement, (Section 5.2.4, step 1).

2) Voltage coefficient* of the current source when dividing (step 2).

3) Accuracy of the adjustment (step 3).

4) Input amplifier voltage and current offset (affects all three steps).

The EG&G Model 930A Picoammeter accuracy specifications include these contributions to error in the worst cumulative case using the EG&G Model 601A Pico Calibrator as the current source.

* The use of 1 ppm/volt resistors in all EG&G products precludes nonlinear resistance errors.

6. OPTIONAL DIGITAL OUTPUTS

6.1 GENERAL

As indicated in the specifications (Section 1.3.6), the standard Model 930A Picoammeter provides only one digital output -- that for remote polarity monitoring. Optional digital outputs for the 930A are:

OPTION	CODE	ZONE
01	1248	----
02	straight-wired, no buffer, no print-rate control.	----
03	122'4	----
A	----	+Z 1P
B	----	+Z 1N
C	----	-Z 1P
D	----	-Z 1N

Combinations of the above options currently available are:

OPTION	CODE	ZONE	OUTPUT LEVELS
01A*	1248	+Z 1P	True > 3.5v, False < +1v
03A	122'4	+Z 1P	True > 3.5v, False < +1v
01C	1248	-Z 1P	True > +2v, False < -12v
03C	122'4	-Z 1P	True > +2v, False < -12v
02	----	----	True < +1v, False > +3.5v

* Option 01A is directly compatible with all EG&G couplers and with Hewlett-Packard printer, model N39-562A.

Descriptions of options currently available:

OPTION	FUNCTION	P.C. BOARD	REFERENCE
01A	Hex D Inverter	152	Dwgs. 27 & 28, App. A
	Print Control and Range Decoder	154	Dwgs. 29 & 30, App. A
03A	$\bar{1}\bar{2}\bar{4}\bar{8}$ to 122'4 Converter	169	Dwgs. 43 & 44, App. A
	Print Control and Range Decoder	170	Dwgs. 41 & 42, App. A
01C	Hex D Inverter	152	Dwgs. 31 & 32, App. A
	Print Control and Range Decoder	154	Dwgs. 35 & 36, App. A
	Hex D Converter (01C & 03C)	152	Dwgs. 33 & 34, App. A
	Range Converter (01C & 03C)	152	Dwgs. 37 & 38, App. A
03C	$\bar{1}\bar{2}\bar{4}\bar{8}$ to 122'4 Converter	169	Dwgs. 47 & 48, App. A
	Print Control and Range Decoder	170	Dwgs. 45 & 46, App. A
	Hex D Converter (03C & 01C)	152	Dwgs. 33 & 34, App. A
	Range Converter (03C & 01C)	152	Dwgs. 37 & 38, App. A
02A	Hex D Jumper Card	152	Dwg. 39, App. A
	Range Jumper Card	152	Dwg. 40, App. A

6.2 OPTION 01

6.2.1 Digital Output Description

Three full digits; code is NBCD 8421.
One overrange digit, 0 or 1.
Maximum display, 1.999.
Print command rate - 10 Hz to 0.25 Hz(F)*.
Hold-off input voltage (-5v) holds all digital data static until signal is removed.

6.2.2 Truth Tables and Data Format

Table 6.1 Option 01, Mantissa (NBCD) Truth Table.

Digit	Code			
	1	2	4	8
0	0	0	0	0
1	1	0	0	0
2	0	1	0	0
3	1	1	0	0
4	0	0	1	0
5	1	0	1	0
6	0	1	1	0
7	1	1	1	0
8	0	0	0	1
9	1	0	0	1

Data Format

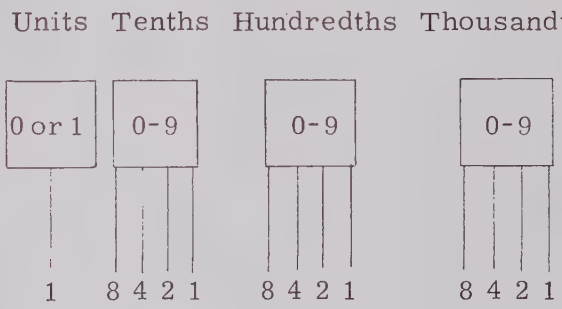
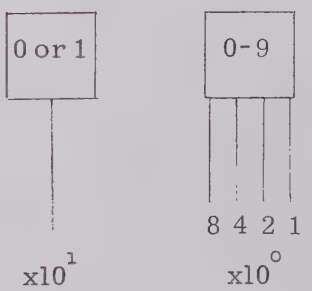


Table 6.2 Option 01, Range Truth Table.

Range	Code				
	1	2	4	8	1x10
10^{-2}	0	1	0	0	0
10^{-3}	1	1	0	0	0
10^{-4}	0	0	1	0	0
10^{-5}	1	0	1	0	0
10^{-6}	0	1	1	0	0
10^{-7}	1	1	1	0	0
10^{-8}	0	0	0	1	0
10^{-9}	1	0	0	1	0
10^{-10}	0	0	0	0	1
10^{-11}	1	0	0	0	1

Data Format



*Fast/Slow switch located internally on recycle rate control p.c. board.

Table 6.3 Option 01, Polarity Truth Table.

Polarity	Code
+	0
-	1

6.2.3 Input/Output Access

The input and output pin locations for Option 01 (and 03) are shown in Table 6.4. Items pertaining to Option 03 are marked with a double asterisk. Also note that pin connections 3 and 4 are specified for Option (suffix) A only.

Table 6.4 Option 01 (and 03) PRINTER Connector (J-4) Pin Designations.

Pin	Designations		Pin	Designations	
1	print command output		13	1	
2	hold input		14	2	
3	"1" ref. level	Suffix A* only	15	4, (2')**	Mantissa tenths
4	"0" ref. level		16	8, (4')**	
5	common		17	1	
6	overrange digits (units)		18	2	
7	polarity		19	4, (2')**	Mantissa hundredths
8	1×10^{1}		20	8, (4')**	
9	1		21	1	
10	2		22	2	
11	4, (2')**	Range	23	4, (2')**	Mantissa thousandths
12	8, (4')**		24	8, (4')**	

(Note: The remote Recycle Command Input is located at pin 13 of the ACCESSORY connector, J-3.)

6.2.4 Input/Output Control Signal Levels

Refer to Figure 6.1 for the time relationships between control signals. Control signal levels for Option 01 (and 03) are:

1) Print command level
   a) level change -- >+5v to 0v (0v=PRINT)
   b) leading edge -- 150ns, 10-90%

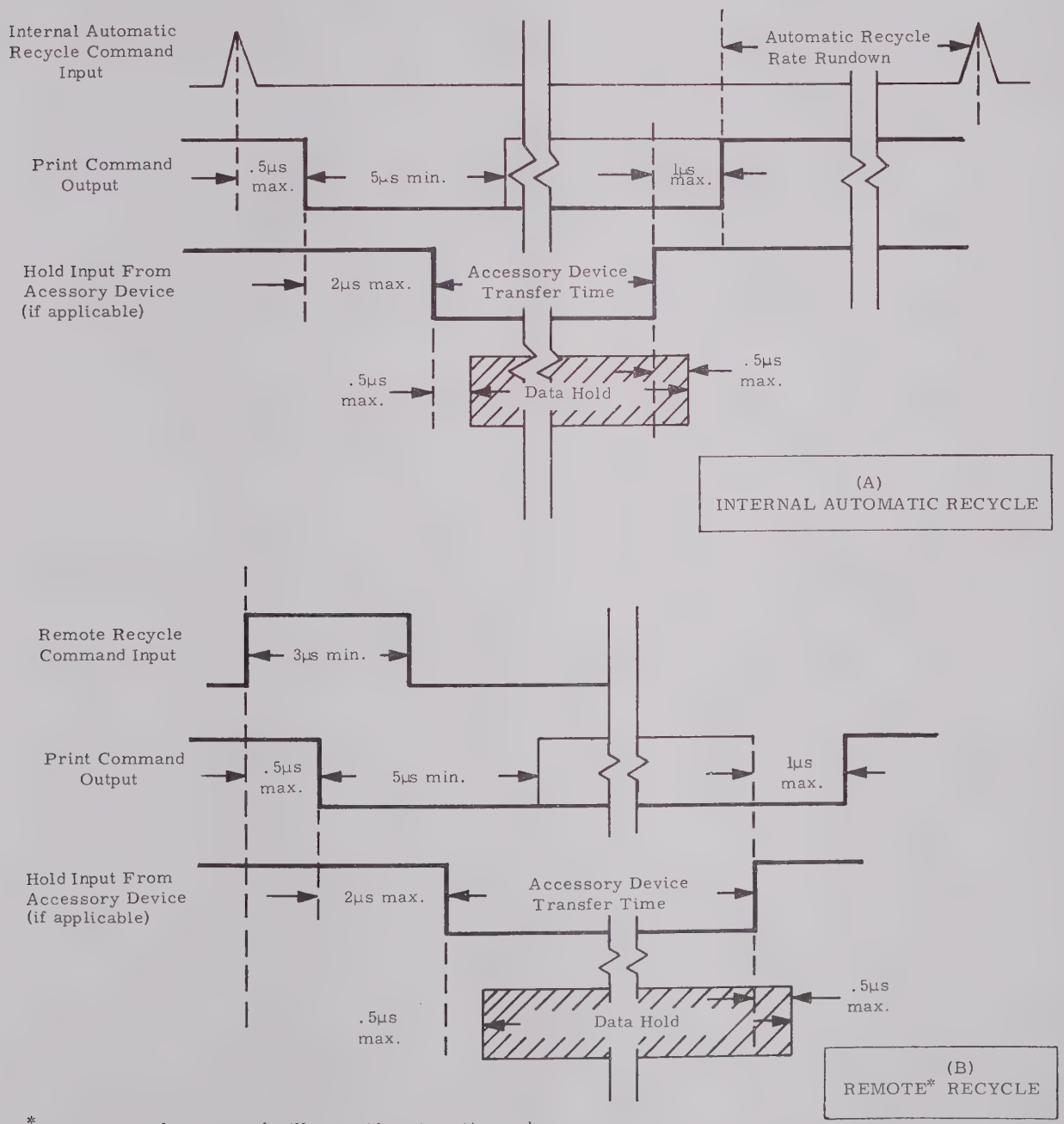
2) Hold input
   a) level change -- 0v to <-.5v (-5.0v = HOLD)

3) Remote recycle command input
   a) level change -- 0v to >4.0v (+4v = RECYCLE)
   b) leading edge -- <1μs 10 - 90%

*For use with HP Printer N39-562A.
**Option 03.

6.2.5 Timing

The time relationships between input and output signals for Options 01 and 03 are identical. Figure 6.1 illustrates these relationships (A) when timing is controlled by the recycle rate control on the front panel of the 930A and (B) when the recycle rate is controlled remotely.



*Remote recycle command will override automatic rundown.

Figure 6.1 Option 01 (and 03) Input / Output Signal Timing.

6.2.6 Data Signal Output Options

Data signal outputs can have various levels and truisms. These levels and truisms are specified by a letter suffix to the option number, e.g., 01A, 03C, etc. The following are specifications for the A and C suffix options presently available.

1) The "A" suffix option specifies positive true, positive zone logic for data outputs as illustrated in Figure 6.2.

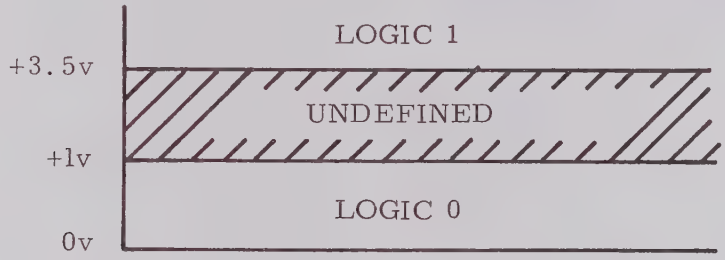


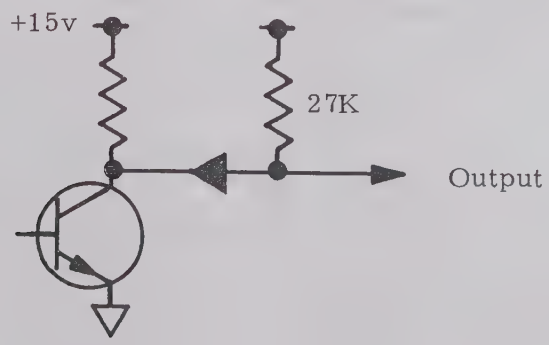
Figure 6.2 Logic Zones for "A" Suffix Option.

Logic level specifications and a typical output circuit for the "A" suffix option are:

a) Logic 1 = > +5v;

b) Logic 0 = < +0.9v;
2 ma sink, max.

c) Typical output circuit:



2) The "C" suffix option specifies positive true, negative zone logic for data outputs as illustrated in Figure 6.3.

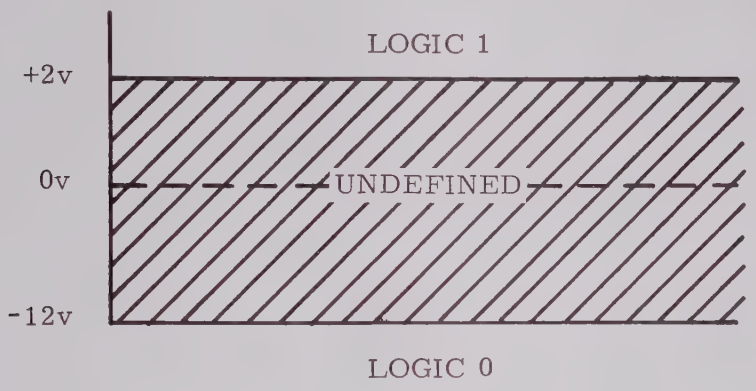


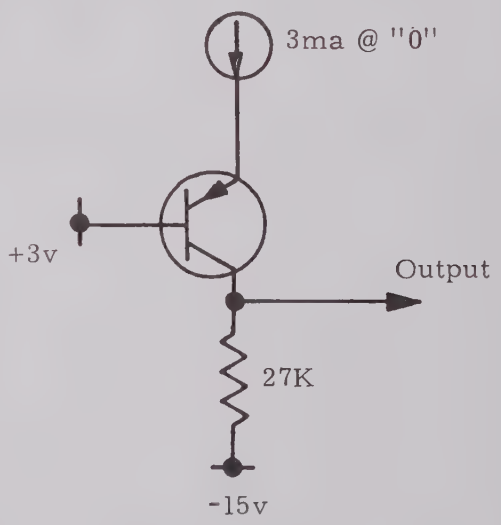
Figure 6.3 Logic Zones for "C" Suffix Options.

Logic level specifications and a typical output circuit for the "C" suffix option are:

a) Logic 1 = > +2.5v;
2 ma sink, max.

b) Logic 0 = > -12.5v;
0.4 ma source, max.

c) Typical output circuit:



6.3 OPTION 03

6.3.1 Digital Output Description

Same as Option 01, except for the output code which is BCD, 42'21.

6.3.2 Truth Tables and Data Format

Table 6.5 Option 03, Mantissa (BCD) Truth Table.

Digit	Code			
	1	2	2'	4
0	0	0	0	0
1	1	0	0	0
2	0	1	0	0
3	1	1	0	0
4	0	1	1	0
5	1	1	1	0
6	0	0	1	1
7	1	0	1	0
8	0	1	1	1
9	1	1	1	1

Data Format

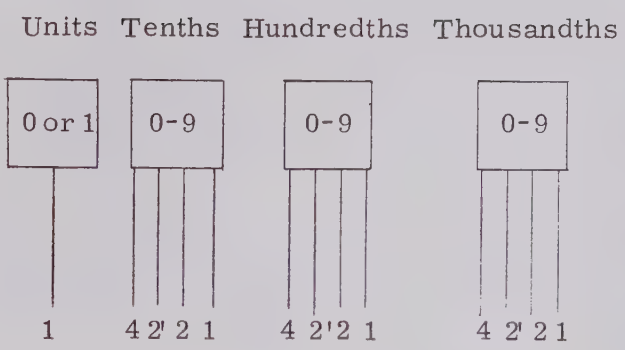


Table 6.6 Option 03, Range Truth Table .

Range	Code				
	1	2	2'	4	1x10
10^{-2}	0	1	0	0	0
10^{-3}	1	1	0	0	0
10^{-4}	0	1	1	0	0
10^{-5}	1	1	1	0	0
10^{-6}	0	0	1	1	0
10^{-7}	1	0	1	1	0
10^{-8}	0	1	1	1	0
10^{-9}	1	1	1	1	0
10^{-10}	0	0	0	0	1
10^{-11}	1	0	0	0	1

Data Format

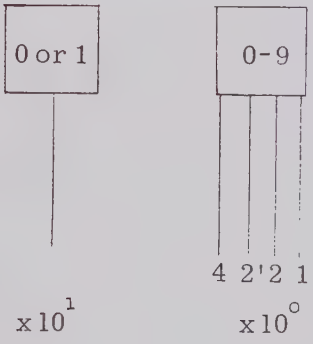


Table 6.7 Option 03, Polarity Truth Tables

Polarity	Code
+	0
-	1

6.3.3 Input/Output Access

The input/output pin designations for Option 03 are shown in Table 6.4, Section 6.2.1.

6.3.4 Input/Output Control Signal Levels

Signal levels for Option 03 are identical with those for Option 01.

6.3.5 Timing

The time relationships between input and output signals for Option 03 are identical with those for Option 01. Refer to Section 6.2.5.

6.4 OPTION 02

6.4.1 Digital Output Description

Option 02 provides non-buffered digital outputs from the 930A for current and range exponent displays. No output timing signals are provided from the 930A.

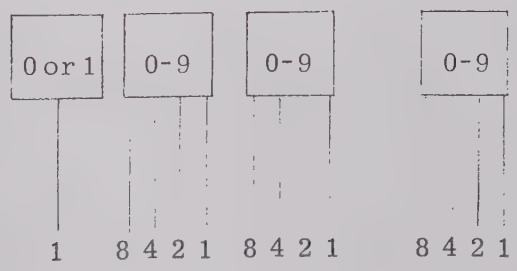
Logic code for the current is positive zone, negative true, NBCD 8421. Logic code for range exponent is positive zone, negative true, -2 NBCD, 8421 (See output Truth Tables).

6.4.2 Truth Tables and Data Format

Table 6.8 Option 02, Mantissa (NBCD) Truth Table.

Digit	Code			
	1	2	4	8
0	0	0	0	0
1	1	0	0	0
2	0	1	0	0
3	1	1	0	0
4	0	0	1	0
5	1	0	1	0
6	0	1	1	0
7	1	1	1	0
8	0	0	0	1
9	1	0	0	1

Data Format



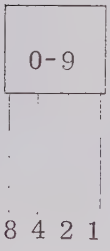
Logic 1 < +0.9 v , Logic 0 > .45v

Table 6.9 Option 02, Range Truth Table.

Range	Code			
	1	2	4	8
10^{-2}	0	0	0	0
10^{-3}	1	0	0	0
10^{-4}	0	1	0	0
10^{-5}	1	1	0	0
10^{-6}	0	0	1	0
10^{-7}	1	0	1	0
10^{-8}	0	1	1	0
10^{-9}	1	1	1	0
10^{-10}	0	0	0	1
10^{-11}	1	0	0	1

Logic 1 < +0.9v and logic 0 > +4.5v

Data Format



$x10^{\circ}$ -2

Table 6.10 Option 02, Polarity Table

Polarity	Code
+	1
-	0

6.4.3 Input/Output Access

The input and output pin locations for Option 02 are shown in Table 6.11.

Table 6.11 Option 02, Printer Connector (J-4) Pin Designations.

Pin	Designation	Pin	Designation
1		13	1
2		14	2 } mantissa tenths
3		15	4
4		16	8
5	common	17	1
6	mantissa units	18	2 } mantissa hundredths
7	polarity	19	4
8		20	8
9	1	21	1
10	2 } range exponent	22	2 } mantissa thousandths
11	4	23	4
12	8	24	8

6.4.4 Input/Output Control Signal Levels

Option 02 input/output levels for the mantissa and exponent are:

1) Logic 0 > +4.5v, source 100μa max.

2) Logic 1 < +0.9v, sink 1 ma, max.

7. PARTS REPLACEMENT

7.1 GENERAL

This section contains lists of replaceable parts for the 930A Picoammeter. To obtain replacement parts, address order to inquiry to:

EG&G, INC.
Laboratory Products Division
P.O. Box 755
Goleta, California 93017

To obtain parts not listed in this manual, the following information should be included when ordering.

1) Instrument model number.

2) Instrument serial number.

3) Description, function, and location of part.

7.2 PARTS LISTS

The following parts lists are correlated with the assembly drawings in Appendix A. The parts are identified by item number or component name and listed numerically by EG&G part number.

PICOAMMETER 930A DWG. 1, APP. A

Component or Item No.	EG&G Part No.	Description
43	140-0510	Bracket, angle 1/2 x 1/2
35	210-0512	Connector, BNC
34	210-0512	Connector, P.C.
50	210-1004	Standoff
33	210-1610	Cap BNC
14	210-2004	A/D Converter Conn. B.D., PB-158
13	250-0058	Range Control Conn. B.D., PB-156
2	250-0057	Front Panel, Fin, PD-4086
5	250-0605	Bracket, Panel, PC-4134
23	250-0608	Lens, PC-4096
81	320-0005	Panel, False, PD-4254
83	250-0627	Panel, False, PD-4092
9	250-0627	Panel, Rear, PD-4269
10	250-0672	Card Retainer
66	250-0696	Panel, Side(right), PD-4321
65	250-0777	Panel, Side(left), PD-4320
82	250-0778	Strip, PC-4270
55	250-5016	Panel, Bearing
11	255-0026	Fan
71	260-0001	Washer, Flat A1, 1/2 x .016 thick
41	280-0326	Insulator
48	280-0404	Washer, Flat, Fiber #4
64	280-0406	Spacer, #4-40NC x 3/8
54	280-0725	Bushing Extender
32	470-0805	Res. 6.2K, 1w +10% (power supply)
52	470-5344	Pot, 5K
53	470-5128	Pot, 25K
39	510-0603	Contact, Switch (N.O.)

PICOAMMETER 930A (cont'd.) DWG. 1, APP. A

Component or Item No.	EG&G Part No.	Description
44	510-0604	Contact, Switch (N.C.)
38	510-0608	Switch
47	510-0612	Button, Push(off), PA-4196
29	510-0613	Button, Push(Man), PA-4197
30	510-0614	Button, Push(Auto), PA-4198
31	510-0615	Button, Push (Rem), PA-4199
45	510-0616	Button, Push (Increase), PA-4200
46	510-0617	Button, Push (Decrease), PA-4201
42	510-1102	Fuse, 1 1/2 amp
40	510-1601	Fuse Holder
26	570-1002	Readout Tube, NL 842
24	570-1003	Readout Tube, NL 843
25	570-1005	Readout Tube, NL 840
78	600-0001	Cable, Coaxial
19	600-1101	Clamp, Cable, 5/16 I.D.
37	600-1102	Clamp, Cable, 5/32 I.D.
22	700-0031	Decoder/Driver, PC-3000
21	700-0032	Range Control, PC-3136
17	700-0037	D/A Converter, 13 Bits, PC-3007
16	700-0040	ADC Control, PC-3134
20	700-0041	Absolute Value, PC-3135
15	700-0065	A/D Converter Ampl., PC-3131
18	700-0060	Fwd-Rev DCU, PC-3078
28	700-0095	Digital Display, PD-3084
12	700-0201	Power Supply, PD-1023
7	700-0121	Feedback Assembly, PD-1054
73		Nut, Hex Hd., #2-56 NC
74		Nut, Hex Hd., #4-40NC

PICOAMMETER 930A (cont'd.) DWG. 1, APP. A

Component or Item No.	EG&G Part No.	Description
57		Screw, Bind Hd., #2-56 NC x 5/16
59		Screw, Bind Hd., #4-40 NC x 3/8
63		Screw, Bind Hd., #6-32 NC x 3/16
60		Screw, Bind Hd., #6-32 NC x 3/16
68		Washer, Lock #2
69		Washer, Lock #4
70		Washer, Lock #6
79		Wire, Bus #22, Copper
80		Wire, Teflon, #22 Stranded
67		Washer, Flat #4

POWER SUPPLY PS-1 DWG. 3, APP. A

Component or Item No.	EG&G Part No.	Description
33	210-1610	Terminals, Insul.
1	250-0648	Power Supply Chassis
15	280-0713	Spacer, Hex #4-40 NC x 1
16	280-0714	Spacer, Hex #8-32 NC x 5/8
13	280-0724	Spacer, Hex #6-32 NC x 5/8 M/F
14	280-0761	Spacer, Hex #4-40 NC x 1 1/8 M/F
11	470-1301	Res. 3 Ω, 5w
10	470-1302	Res. 5 Ω, 5w
9	480-6002	Transistor 40325
8	485-0002	Heatsink
12	510-0902	Thermal Switch
7	560-0001	Transformer
3	700-0038	Power Supply Regulator, P.C. Board
17		Screw, Bind Hd., #6-32 NC x 1/2
18		Screw, Bind Hd., #4-40 NC x 3/8
19		Screw, Bind Hd., #4-40 NC x 1/4
20		Screw, Bind Hd., #8-32 NC x 1/4
34		Screw, Bind Hd., #6-32 NC x 5/16
21		Washer, Int. Tooth #6
22		Washer, Int. Tooth #4
23		Washer, Int. Tooth #8
24		Nut, Hex #4-40 NC
25		Tra-Bond (Meg #2122)
26		Nut, Hex #6-32 NC
27		Wire Teflon, #22 Stranded (Blk) 4"
28		Wire Teflon, #22 Stranded (Yel) 4"
29		Wire Teflon, #22 Stranded (Blu) 4"
30		Wire Teflon, #22 Stranded (Grn) 4"

POWER SUPPLY PS-1 (cont'd.) DWG. 3, APP. A

Component or Item No.	EG&G Part No.	Description
31		Lug, Solder
32		Washer, Flat #4

POWER SUPPLY (PS-1) REGULATOR DWG. 6, APP. A

Component or Item No.	EG&G Part No.	Description
C3,6	150-0026	Capacitor, Cer Disc, .01µf
C2,5	150-0112	Capacitor, Electr., 1100µf, 50v
C4,7	150-0113	Capacitor, Electr., 150µf, 30v
C1	150-0114	Capacitor, Electr., 100µf, 250v
PC-134A	250-0038	Printed Circuit Board
R6	470-0008	Res. 82 Ω, 1/4w, 5%
R19	470-0009	Res. 120Ω, 1/4w, 5%
R29	470-1914	Res. 750Ω, 1/4w, 5%
R31	470-0806	Res. 150K, 1w, 10%
R30	470-1003	Res. 200Ω, 1/4w, 5%
R4, 17	470-1015	Res. 820Ω, 1/4w, 5%
R20, 22	470-1017	Res. 1K, 1/4w, 5%
R21	470-1020	Res. 1.3K, 1/4w, 5%
R7, 8	470-1021	Res. 1.5K, 1/4w, 5%
R3, 16	470-1030	Res. 4.7K, 1/4w, 5%
R23	470-1032	Res. 5.6K, 1/4w, 5%
R24, 27	470-1034	Res. 6.8K, 1/4w, 5%
R9, 10	470-1037	Res. 11K, 1/4w, 5%
R12	470-1040	Res. 15K, 1/4w, 5%
R11, 14	470-2187	Res. 750Ω, 1/2w, 1%
R25	470-2188	Res. 301Ω, 1/2w, 1%
R24	470-2189	Res. 475K, 1/2w, 1%
R13, 26	470-5318	Pot, 100Ω
CR10, 17	480-1101	Diode, 1N4148
CR9, 16, 18	480-1407	Diode, Zener, 1N704
CR11	480-1408	Diode, Zener, 1N713
CR19	480-1410	Diode, 1N936
CR1-8,	480-1505	Diode, SCE-2

POWER SUPPLY (PS-1) REGULATOR (cont'd.) DWG. 6, APP. A

Component or Item No.	EG&G Part No.	Description
CR12-15	480-1505	Diode, SCE-2
Q6	480-5301	Transistor, 2N3417
Q4	480-5303	Transistor, 2N3415
Q9	480-5805	Transistor, 2N5805
Q5, 10	480-6002	Transistor, Dual NPN
Q3	480-6004	Transistor, RCA 40324
Q1	480-6005	Transistor, 2N4356
Q8	480-6006	Transistor TQ59
	210-1336	Socket, Transistor, TO-18 INLINE
	210-1333	Socket, Transistor, TO-18
	210-1335	Socket, Transistor, Dual-3, TO-66
	210-1330	Socket, Transistor, Four Lead, TO-5
		Screw, BN. ND #6-32 NCX
		Nut, Hex #6-32 NC

ABSOLUTE VALUE DWG. 10, APP. A

Component or Item No.	EG&G Part No.	Description
C2	150-0021	Capacitor, Cer Disc, 91pf
C3	150-0027	Capacitor, Cer Disc, .005µf
C1	150-0109	Capacitor, Electr., 15µf/15v
C4	150-0210	Capacitor, Foil, 22µf
PB-143	250-0041	Abs. Value, P.C. Bd.
K1	450-0012	Relay, Reed #MOIC124
R8, 9	470-0004	Res. 22K, 1/4w, 5%
R23	470-0401	Res. 75Ω, 1/2w, 5%
R5	470-1003	Res. 200Ω, 1/4w, 5%
R26	470-1008	Res. 330Ω, 1/4w, 5%
R16	470-1010	Res. 430Ω, 1/4w, 5%
R22	470-1013	Res. 680Ω, 1/4w, 5%
R14	470-1017	Res. 1K, 1/4w, 5%
R15	470-1018	Res. 1.1K, 1/4w, 5%
R20	470-1024	Res. 2K, 1/4w, 5%
R7	470-1025	Res. 2.2K, 1/4w, 5%
R30	470-1030	Res. 4.7K, 1/4w, 5%
R1, 4	470-1031	Res. 5.1K, 1/4w, 5%
R17, 19	470-1036	Res. 10K, 1/4w, 5%
R25	470-1038	Res. 12K, 1/4w, 5%
R21	470-1039	Res. 13K, 1/4w, 5%
R14	470-1043	Res. 20K, 1/4w, 5%
R2, 12	470-1047	Res. 33K, 1/4w, 5%
R24	470-1053	Res. 75K, 1/4w, 5%
R6	470-1054	Res. 82K, 1/4w, 5%
R3	470-1057	Res. 150K, 1/4w, 5%
R27	470-1058	Res. 240K, 1/4w, 5%
R13, 29	470-1419	Res. 25K, .01%WW

ABSOLUTE VALUE (cont'd.) DWG. 10, APP. A

Component or Item No.	EG&G Part No.	Description
R18	470-5324	Pot, 10K
CR6	470-1004	Diode, 1N482
CR1-5	470-1101	Diode, 1N4148
Q3	470-5303	Transistor, 2N3415
Q4, 5	470-5304	Transistor, 2N3877A
Q9	480-5308	Transistor, 2N3405
Q8, 2	480-5802	Transistor, 2N3638A
Q7	480-5805	Transistor, EG&G Spec. 5805
Q1, 6	480-6002	Transistor, Dual NPN (EG&G Spec. 6002)
		Screw, Bind Hd., #4-40NC x 1/4
		Nut, Hex #4-40
		Washer, Int. Tooth, #4

ADC DUAL OPERATIONAL AMPLIFIER DWG. 12, APP. A

Component or Item No.	EG&G Part No.	Description
C9, 10, 15	150-0007	Capacitor, Mono, .68µf
C3, 8, 14	150-0012	Capacitor, Cer Disc, .05µf
C15	150-0023	Capacitor, Cer Disc, 200pf
C2, 7	150-0027	Capacitor, Cer Disc, 5000pf
C1	150-0023	Capacitor, Cer Disc, 200pf
C11, 12	150-0109	Capacitor, 15/15v, Electr.
C5	150-0207	Capacitor, Foil, .1µf
C4	150-0210	Capacitor, Foil, .33µf
PB-160	250-0108	P.C. Board
AR1, 2	313-0053	Amplifier, µA709C
R17, 16	470-1021	Res. 1.5K, 1/4w, 5%
R1	470-1034	Res. 6.8K, 1/4w, 5%
R8	470-1051	Res. 51K, 1/4w, 5%
R7, 10, 13	470-2124	Res. M.F., 15K, 1%, 1/4w
R4, 5, 11	470-2128	Res. M.F., 49.9K, 1%, 1/4w
R6, 9, 12	470-2224	Res. 1.62K, 1%, 1/4w
R3	470-2246	Res. 9.09K, 1%, 1/4w
R20	470-2501	Thyrite, GE #67D-5010
R2	470-5322	Pot, 2K
W1-8	600-0628	Buss Wire, 20 gage

ADC CONTROL DWG. 14, APP. A

Component or Item No.	EG&G Part No.	Description
C8	150-0011	Capacitor, Cer Disc, 560pf
C2 4, 10, 14	150-0012	Capacitor, Cer Disc, .05μf, 20v
C15, 17	150-0019	Capacitor, Cer Disc, 30pf
C16, 18	150-0020	Capacitor, Cer Disc, 47pf
C6, 7	150-0021	Capacitor, Cer Disc, 91pf
C11, 12	150-0025	Capacitor, Cer Disc, 1000pf
C1, 3	150-0105	Capacitor, Electr., 10μf, 15v
C9	150-0204	Capacitor, Flat Foil, .033μf, 250v
TP1	210-1626	Test Jack, 11105
PB-139	250-0040	P.C. Board
R52	470-0005	Res 3 9K, 5%, 1/4w
R8	470-0006	Res. 330K, 5%, 1/4w
R28	470-0007	Res. 2.7K, 5%, 1/4w
R12, 55	470-1002	Res. 100Ω, 5%, 1/4w
R33	470-1015	Res. 820K, 5%, 1/4w
R14, 17, 18, 29, 30	470-1017	Res. 1K, 5%, 1/4w
R7, 13	470-1027	Res. 3K, 5%, 1/4w
R25	470-1028	Res. 3.3K, 5%, 1/4w
R10, 11, 23, 24	470-1029	Res. 4.3K, 5%, 1/4w
R6, 9, 15, 44, 47	470-1031	Res. 5.1K, 5%, 1/4w
R26, 27	470-1034	Res. 6.8K, 5%, 1/4w
R2, 45, 46, 48, 49, 54	470-1036	Res. 10K, 5%, 1/4w
R3, 4, 19, 29, 81, 53	470-1042	Res. 18K, 5%, 1/4w
R21	470-1043	Res. 20K, 5%, 1/4w

ADC CONTROL (cont'd.) DWG. 14, APP. A

Component or Item No.	EG&G Part No.	Description
R57	470-1045	Res. 27K, 5%, 1/4w
R1, 5, 22	470-1046	Res. 30K, 5%, 1/4w
R16	470-1050	Res. 47K, 5%, 1/4w
R43, 56	470-1051	Res. 51K, 5%, 1/4w
R42, 50	470-1052	Res. 68K, 5%, 1/4w
R40	470-1054	Res. 82K, 5%, 1/4w
R34	470-2116	Res. 1K, 1%, 1/4w
R35	470-2123	Res. 10K, 1%, 1/4w
R39	470-2151	Res. 121K, 1%, 1/4w
R41	470-5325	Pot, Beckman, 20K, #78P
CR1-20	480-1101	Diode, 1N4148
Q15, 16	480-5304	Transistor, 2N3877A
Q1, 4-6, 8, 10, 12-14	480-5806	Transistor, 2N2369
Q2, 3, 7, 9, 11	480-5804	Transistor, 2N3640 (EG&G Spec.5804)
R38	470-0004	Res. 22K, 5%, 1/4w

A/D CONVERTER INTERCONNECT DWG. 15, APP. A

Component or Item No.	EG&G Part No.	Description
J1-7	210-1004	Connector, 15-Pin
PD-158	250-0058	P.C. Board
R1	470-1078	Res. 3.3K, 5%, 1/4w

D/A CONVERTER, 13-BIT DWG. 17, APP. A

Component or Item No.	EG&G Part No.	Description
PB-107	250-0037	P.C. Board
R56	470-1013	Res. 680Ω, 5%, 1/4w
R1, 5, 9, 13, 17, 21, 25, 29, 33, 38, 43, 48, 52	470-1026	Res. 2.4K, 5%, 1/4W
R54	470-1036	Res. 10K, 5%, 1/4w
R50	470-1038	Res. 12K, 5%, 1/4w
R45	470-1044	Res. 24K, 5%, 1/4w
R2, 6, 10, 14, 18, 22 26, 30, 34, 39, 40, 44, 49, 53	470-1051	Res. 51K, 5%, 1/4w
R35	470-1055	Res. 100K, 5%, 1/4w
R31	470-1056	Res. 120K, 5%, 1/4w
R27	470-1058	Res. 240K, 5%, 1/4w
R3, 7, 11 15, 19, 23	470-1059	Res. 470K, 5%, 1/4w
R20	470-1214	Res. 2M, M.F., 5%, 1/4w
	470-1215	Res. 2.5M, M.F., 5%, 1/4w
R12	470-1216	Res. 5M, M.F., 1%, 1/4w
R8	470-1217	Res. 10M, 1%, 1/4W
R4	470-1218	Res. 20M, 1%
R24	470-1411	Res. 1M, W.W., 1%, 1/4w
R28	470-1412	Res. 500K, .05%, 1/4w
R32	470-1415	Res. 250K, W.W., .01%
R36	470-1416	Res. 200K, W.W., .01%, 1/4w
R41	470-1417	Res. 100K, W.W., .02%, 1/4w
R46	470-1418	Res. 50K, W.W., .01%, 1/4w

D/A CONVERTER - 13 BIT (cont'd.) DWG. 17, APP. A

Component or Item No.	EG&G Part No.	Description
R51	470-1419	Res. 25K, W.W., .01%, 1/4w
R55	470-1420	Res. 20K, W.W., .01%, 1/4w
CR27	480-1410	Diode, 1N936
Q1-26	480-5303	Transistor, 2N3415

FWD. - REV. DECIMAL COUNTING UNIT DWG. 19, APP. A

Component or Item No.	EG&G Part No.	Description
C1, 6, 22	150-0012	Capacitor, Cer Disc, .05μf
C11-20	150-0013	Capacitor, Cer Disc, 68pf
C7, 10	150-0018	Capacitor, Cer Disc, 15pf
C2-5, 9, 8	150-0019	Capacitor, Cer Disc, 30pf
PB-116	250-0060	P.C. Board
R67, 68	470-0004	Res. 22K, 5%, 1/4w
R1	470-1004	Res. 220Ω, 5%, 1/4w
R74	470-1016	Res. 910Ω, 5%, 1/4w
R2, 3	470-1019	Res. 1.2K, 5%, 1/4w
R28, 35, 42, 49, 56	470-1021	Res. 1.5K, 5%, 1/4w
R63, 64	470-1024	Res. 2K, 5%, 1/4w
R10, 11 14, 15, 24-27,	470-1027	Res. 3K, 5%, 1/4w
R9, 13	470-1028	Res. 3.3K, 5%, 1/4w
R8, 12	470-1030	Res. 4.7K, 5%, 1/4w
R31-34, 38-41, 45-48, 52-55, 59-62	470-1033	Res. 6.2K, 5%, 1/4w
R4, 5	470-1036	Res. 10K, 5%, 1/4w
R6, 7, 30 37, 44, 51, 57, 58, 29, 36, 43, 50, 69-73	470-1039	Res. 13K, 5%, 1/4w
R65, 66	470-1040	Res. 15K, 5%, 1/4w
R16, 18, 20, 22,	470-1041	Res. 16K, 5%, 1/4w

FWD.-REV. DECIMAL COUNTING UNIT (cont'd) DWG. 19, APP. A

Component or Item No.	EG&G Part No.	Description
R17, 19, 21, 23	470-1048	Res. 36K, 5%, 1/4w
R75, 76	470-1049	Res. 39K, 5%, 1/4w
CR10, 12	480-1004	Diode, 1N482
CR11, 13-20, 1-6, 9, 22, 23, 28, 29, 31-41, 25, 26, 1-11.	480-1101	Diode, 1N4148
Q1-11, 15-18.	480-5806	Transistor, 2N2369

RANGE CONTROL DWG. 21, APP. A

Component or Item No.	EG&G Part No.	Description
C12, 15	150-0005	Capacitor, Mono, 0.1μf
C1, 2	150-0007	Capacitor, Mono, .68μf
C5-7, 10, 11, 13, 14 16	150-0012	Capacitor, Mono, .05μf
C3,4	150-0024	Capacitor, Cer Disc, 300 pf
C3, 4	150-0212	Capacitor, Foil, 68μf
PB-101	250-0032	Range Control
R35	470-0010	Res. 470Ω, 5%, 1/4w
R17, 23	470-1004	Res. 220Ω, 5%, 1/4w
R22; 28	470-1015	Res. 820Ω, 5%, 1/4w
R30, 33	470-1017	Res. 1K, 5%, 1/4w
R1, 48	470-1024	Res. 2K, 5%, 1/4w
R16	470-1025	Res. 2.2K, 5%, 1/4w
R15	470-1026	Res. 2.4K, 5%, 1/4w
R20, 26	470-1028	Res. 3.3K, 5%, 1/4w
R11, 2,18, 24, 36-39 41-45, 47	470-1031	Res. 5.1K, 5%, 1/4w
R40, 46	470-1036	Res. 10K, 5%, 1/4w
R21,27,29, 31, 32, 34	470-1040	Res. 15K, 5%, 1/4w
R13, 14	470-1041	Res. 16K, 5%, 1/4w
R4, 6	470-1043	Res. 20K, 5%, 1/4w
R2, 7, 9	470-1045	Res. 27K, 5%, 1/4w
R19, 25	470-1051	Res. 51K, 5%, 1/4w
R5, 10	470-1055	Res. 100K, 5%, 1/4w
R8	470-5324	Pot, Beckman, 10K, #78P
R3	470-5325	Pot, Beckman, 20K

RANGE CONTROL (cont'd.) DWG. 21, APP. A

Component or Item No.	EG&G Part No.	Description
CR2-27	478-1101	Diode, 1N4148
Q1, 3, 4	480-5303	Transistor, 2N3415
Q5-12	480-5803	Transistor, 2N3646
Q2	480-5805	Transistor, (EG&G Spec. 5805)

RANGE CONTROL INTERCONNECT DWG. 22, APP. A

Component or Item No.	EG&G Part No.	Description
J10, 11, 12	210-1004	Connector, 15-Pin
PD-156	250-0057	P.C. Board

DECODER/DRIVER, ME 900 DWG. 24, APP. A

Component or Item No.	EG&G Part No.	Description
C1, 2, 3	150-0012	Capacitor, Cer Disc, .05µf
PB-100	250-0031	P.C. Board
R36	470-1001	Res. 10K, 5%, 1/4w
R2, 5, 8, 11, 14	470-1031	Res. 5.1K, 5%, 1/4w
R16-26	470-1040	Res. 15K, 5%, 1/4w
R1, 4, 7, 10, 13	470-1046	Res. 30K, 5%, 1/4e
R3, 6, 9, 12, 15	470-1054	Res. 82K, 5%, 1/4w
CR1-62	480-1101	Diode, 1N4148
Q1-15	480-5303	Transistor, 2N3415

DIGITAL DISPLAY, PB-142 DWG. 26, APP. A

Component or Item No.	EG&G Part No.	Description
PC-142	250-0095	P.C. Board
IC1-4	313-0027	Dec. Drive
R26-29,	470-0006	Res. 330K, 5%, 1/4w
R1-5, 7, 8	470-0801	Res. 15K, 5%, 1w
R6	470-0802	Res. 12K, 5%, 1w
R9-20, 22-25	470-1030	Res. 4.7K, 5%, 1/4w
R21	470-1050	Res. 47K, 5%, 1/4w
R30-33	470-1052	Res. 68K, 5%, 1/4w
CR2	480-1409	Diode, 1N3789
CR1	480-1505	Diode, SCE-2
Q1	480-5701	Transistor, (#F.S.19771)
V2	570-1002	Readout Tube
V1	570-1003	Readout Tube
V3-7	570-1005	Readout Tube
XV1-7	570-1501	Socket

OPTION 01A, HEX D INVERTER DWG. 28, APP. A

Component or Item No.	EG&G Part No.	Description
PB-152	250-0053	P.C. Board
R25	470-1003	Res. 10K, 5%, 1/4w
R27	470-1007	Res. 300Ω, 5%, 1/4w
R26	470-1020	Res. 4.3K, 5%, 1/4w
R1-12	470-1045	Res. 27K, 5%, 1/4w
R13-24	470-1050	Res. 47K, 5%, 1/4w
CR1	480-1505	Diode, 1N4002/SCE-2
Q1-12	480-5303	Transistor, 2N3415

OPTION 01A, PRINT CONTROL & RANGE DECODER DWG. 30, APP. A

Component or Item No.	EG&G Part No.	Description
R1, 5, 9 13, 17,21, 22	470-1050	Res. 47K, 5%, 1/4w
R40	470-1046	Res. 30K, 5%, 1/4w
R4, 8, 12, 16, 20,25, 30	470-1045	Res. 27K, 5%, 1/4w
R2, 6, 10, 14, 18,23, 28, 45	470-0004	Res. 22K, 5%, 1/4w
R38	470-1040	Res. 15K, 5%, 1/4w
R3, 7, 11 15, 19,24, 29, 32	470-1036	Res. 10K, 5%, 1/4w
R33	470-1031	Res. 5.1K, 5%, 1/4w
R39, 41, 42	470-1030	Res. 4.7K, 5%, 1/4w
R37	470-0005	Res. 3.9K, 1/4w, 5%
R48	470-1027	Res. 3K, 5%, 1/4w
R47	470-1025	Res. 2.2K, 5%, 1/4w
R36	470-1003	Res. 200Ω, 5%, 1/4w
PB-154	250-0055	P.C. Board

OPTION 01C, HEX D INVERTER DWG. 32, APP. A

Component or Item No.	EG&G Part No.	Description
PB-152	250-0053	P.C. Board
CR1	480-1505	Diode, 1N4002/SCE-2
W1		Wire Buss, 20 gage
Q1-12	480-5303	Transistor, 2N3415
R1-12	470-0005	Res. 3.9K, 5%, 1/4w
R13-24	470-1050	Res. 47K, 5%, 1/4w
R25	470-1003	Res. 10K, 5%, 1/4w
R26	470-1029	Res. 4.3K, 5%, 1/4w
R27	470-1007	Res. 300Ω, 5%, 1/4w

OPTION 01C, 03C HEX D CONVERTER DWG. 34, APP. A

Component or Item No.	EG&G Part No.	Description
PB-152	250-0053	P.C. Board
R26	470-1029	Res. 4.3K, 5%, 1/4w
R1-12	470-1045	Res. 27K, 5%, 1/4w
Q1-12	480-5001	Transistor 2N396A
CR1	480-4102	Diode, 2N746, 3.3v
		Buss Wire, 20 gage

OPTION 01C, PRINT CONTROL & RANGE DECODER DWG. 36, APP. A

Component or Item No.	EG&G Part No.	Description
R1, 5, 9, 13, 17, 21 22	470-1050	Res. 47K, 5%, 1/4w
R40	470-1046	Res. 30K, 5%, 1/4w
R4, 8, 12	470-1045	Res. 27K, 5%, 1/4w
R2, 6, 10, 14, 18, 23 28	470-0004	Res. 22K, 5%, 1/4w
R38	470-1040	Res. 15K, 5%, 1/4w
R3, 7, 11, 15, 19, 24 29, 32	470-1036	Res. 10K, 5%, 1/4w
R33	470-1031	Res. 5.1K, 5%, 1/4w
R39, 41, 42	470-1030	Res. 4.7K, 5%, 1/4w
R16, 20, 25, 30, 37 45	470-0005	Res. 3.9K, 5%, 1/4w
R48	470-1027	Res. 3K, 5%, 1/4w
R47	470-1003	Res. 200Ω, 5 %, 1/4w
PB-154	250-0055	P.C. Board

OPTION 01C, 03C RANGE CONVERTER DWG. 38, APP. A

Component or Item No.	EG&G Part No.	Description
PB-152	250-0053	P.C. Board
R1-12	470-1045	Res. 27K, 5%, 1/4w
Q7-17	480-5001	Transistor, 2N396A
		Buss Wire, 20 gage

OPTION 02A, HEX D JUMPER CARD DWG. 39, APP. A

Component or Item No.	EG&G Part No.	Description
PB-153	250-0053	P.C. Board
W1-12		Buss Wire, 20 gage
W1-12		Sleeve

OPTION 02A, RANGE JUMPER CARD DWG. 40, APP. A

Component or Item No.	EG&G Part No.	Description
PB-153	250-0053	P.C. Board
W1-5		Buss Wire, 20 gage
W1-5		Sleeve

OPTION 03A, PRINT CONTROL & RANGE DECODER DWG. 42, APP. A

Component or Item No.	EG&G Part No.	Description
C3	150-0012	Capacitor, .05μf
C2, 4	150-0105	Capacitor, 10μf, 15v
C1	150-0106	Capacitor, 200μf, 15v
PB-170	250-0145	P.C. Board
IC1, 2	313-0036	Integrated Circuit, Quad 2, Input Gate #323
R21	470-0004	Res. 22K, 5%, 1/4w
R7, 9, 13	470-0005	Res. 3.9K, 5%, 1/4w
R6	470-1002	Res. 100Ω, 5%, 1/4w
R8	470-1003	Res. 200Ω, 5%, 1/4w
R19	470-1025	Res. 2.2K, 5%, 1/4w
R16	470-1027	Res. 3K, 5%, 1/4w
R17, 18	470-1030	Res. 4.7K, 5%, 1/4w
R10	470-1031	Res. 5.1K, 5%, 1/4w
R11	470-1036	Res. 10K, 5%, 1/4w
R20	470-1038	Res. 12K, 5%, 1/4w
R14	470-1040	Res. 15K, 5%, 1/4w
R1-5	470-1045	Res. 27K, 5%, 1/4w
R15	470-1046	Res. 30K, 5%, 1/4w
R12, 22	470-1050	Res. 47K, 5%, 1/4w
CR1-5	480-1101	Diode, 1N4148
Q2-4	480-5803	Transistor, 2N3646
Q1	480-5804	Transistor, (EG&G Spec. 5804)
PB-1		

OPTION 03A, $\overline{1248}$ - 122'4 CONVERTER DWG. 44, APP. A

Component or Item No.	EG&G Part No.	Description
PB-169	250-0140	P.C. Board
IC1-7	313-0036	Integrated Circuit, Quad 2, Input Gate # 323
R15	470-1007	Res. 300Ω, 5%, 1/4w
R14	470-1029	Res. 4.3K, 5%, 1/4w
R13	470-1036	Res. 10K, 5%, 1/4w
R1-12	470-1045	Res. 27K, 5%, 1/4w
CR1, 2, 3	480-1101	Diode, 1N4148
CR4	480-1405	Diode, 1N3789

OPTION 03C, PRINT CONTROL & RANGE DECODER DWG. 46, APP. A

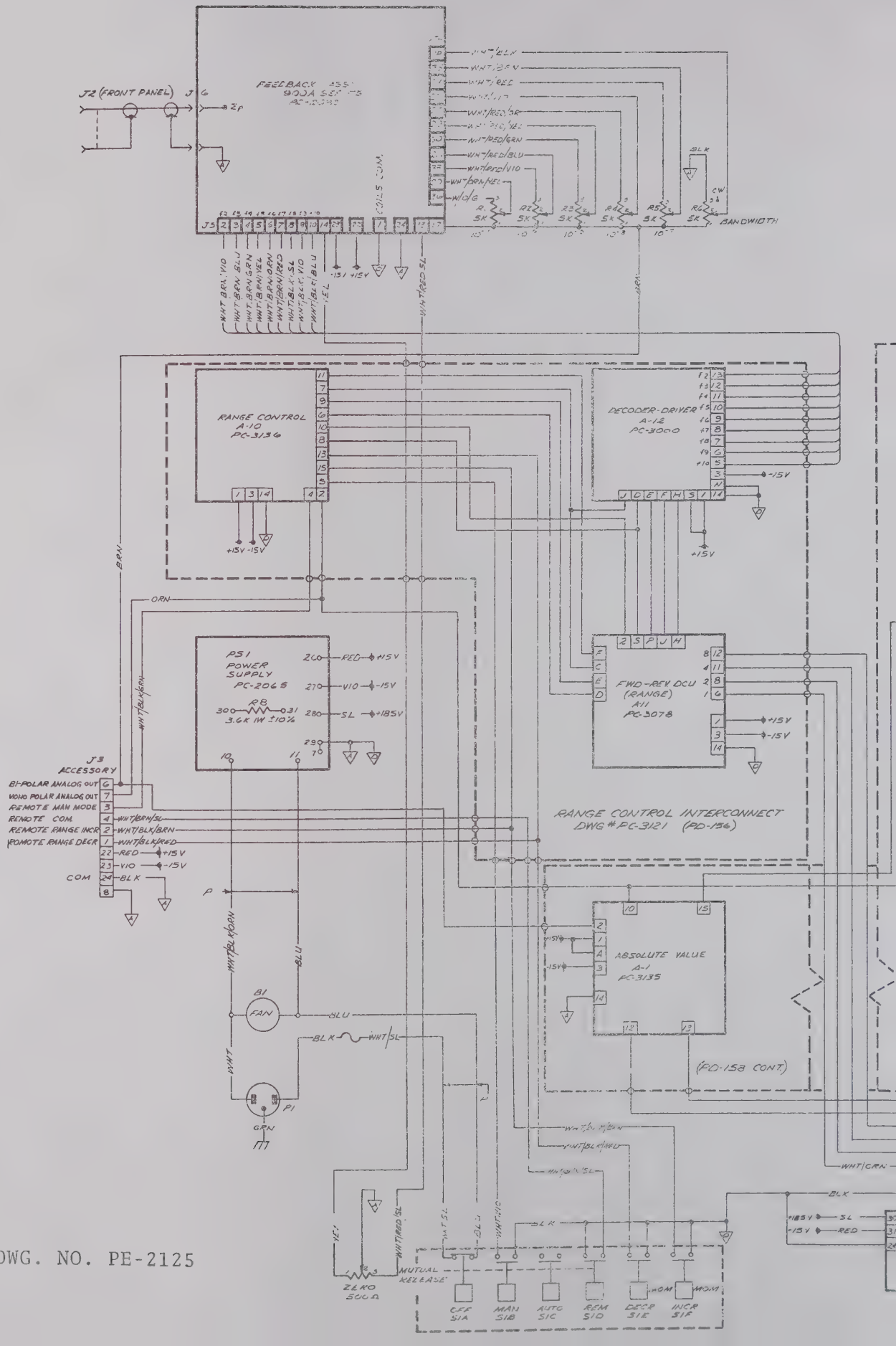
Component or Item No.	EG&G Part No.	Description
C3	150-0012	Capacitor, .05μf
C2, 4	150-0105	Capacitor, 10μf, 15v
C1	150-0106	Capacitor, 200μf, 15v
PB-170	250-0145	P.C. Board
IC1-2	313-0036	Integrated Circuit, Quad 2, Input Gate # 323
B7, 9, 13, 1-5, 21	470-0005	Res. 3.9K, 5%, 1/4w
R6	470-1002	Res. 100Ω, 5%, 1/4w
R8	470-1003	Res. 200Ω, 5%, 1/4w
R19	470-1025	Res. 2.2K, 5%, 1/4w
R16	470-1027	Res. 3K, 5%, 1/4w
R17, 18	470-1030	Res. 4.7K, 5%, 1/4w
R10	470-1031	Res. 5.1K, 5%, 1/4w
R11	470-1036	Res. 10K, 5%, 1/4w
R20	470-1038	Res. 12K, 5%, 1/4w
R14	470-1040	Res. 15K, 5%, 1/4w
R15	470-1047	Res. 33K, 5%, 1/4w
R21, 22	470-1050	Res. 47K, 5%, 1/4w
CR1-4	480-1101	Diode, 1N4148
Q2, 3, 5	480-5803	Transistor, 2N3646
Q1	480-5804	Transistor (EG&G Spec. 5804)

OPTION 03C, $\bar{1}\bar{2}\bar{4}\bar{8}$ - 122'4 CONVERTER DWG. 48, APP. A

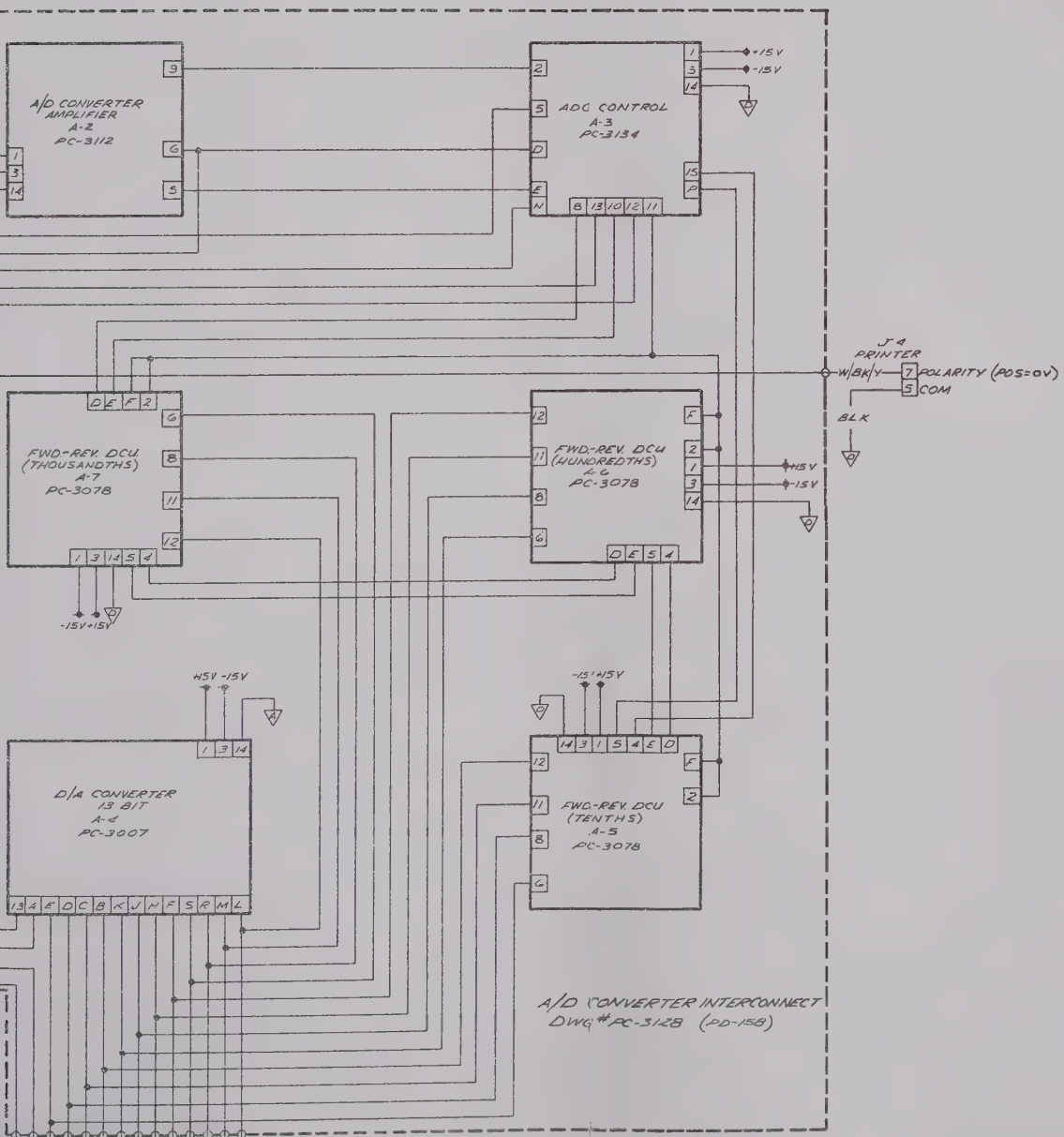
Component or Item No.	EG&G Part No.	Description
PB-169	250-0140	P.C. Board
IC1-7	313-0036	Integrated Circuit, Quad 2, Input Gate # 323
R15	470-1007	Res. 300Ω, 5%, 1/4w
R14	470-1029	Res. 4.3K, 5%, 1/4w
R13	470-1036	Res. 10K, 5%, 1/4w
R1-12	470-1045	Res. 3.9K, 5%, 1/4w
CR1, 2, 3	480-1101	Diode, 1N4148

APPENDIX A

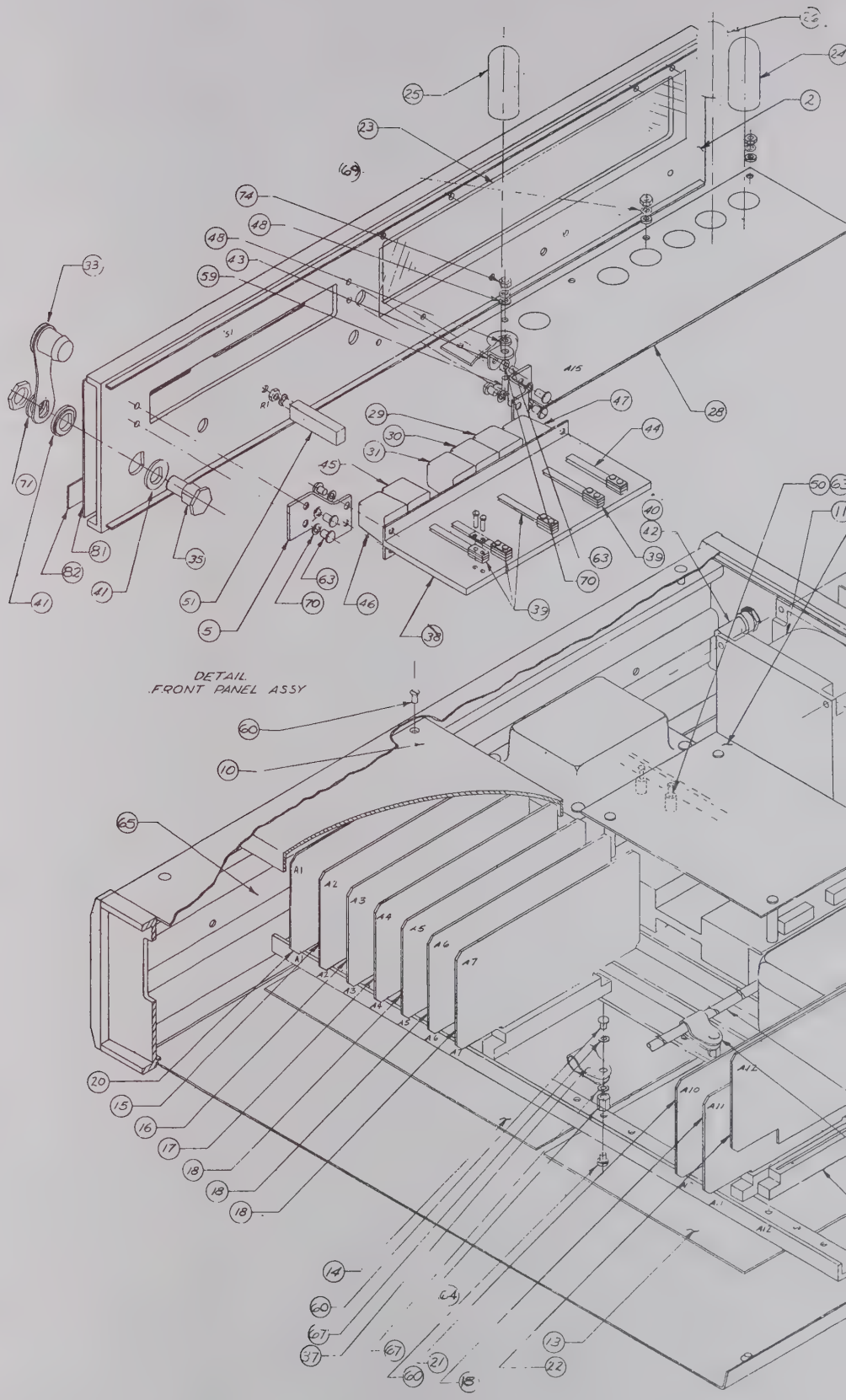
DRAWINGS FOR EG&G PICOAMMETER MODEL 930A



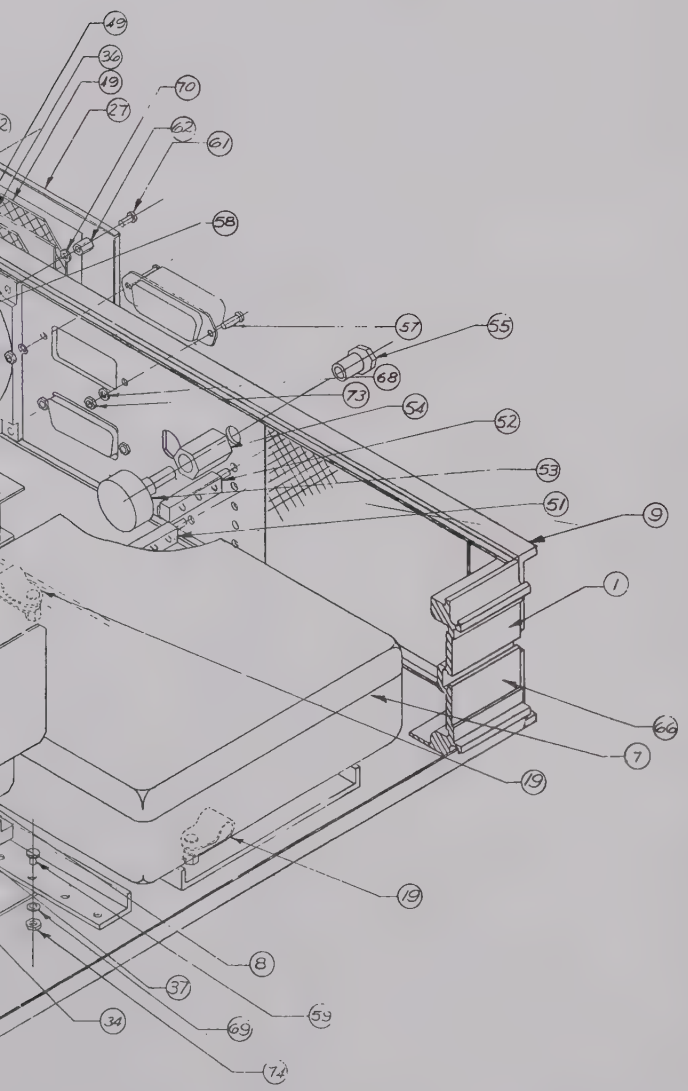
EG&G DWG. NO. PE-2125



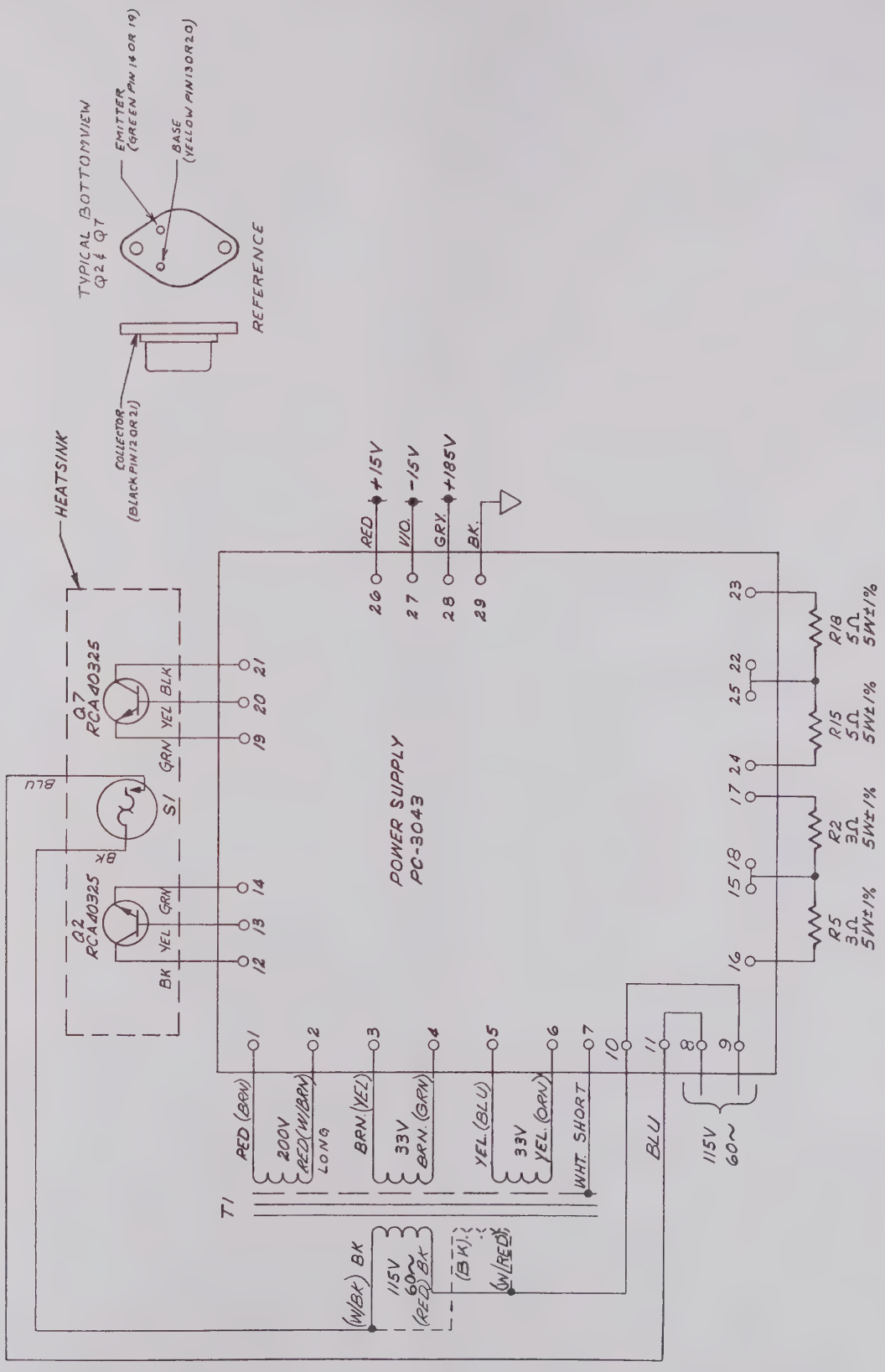
PICOAMMETER 930A SCHEMATIC
DWG. 1



EG&G DWG. NO. PE-1059

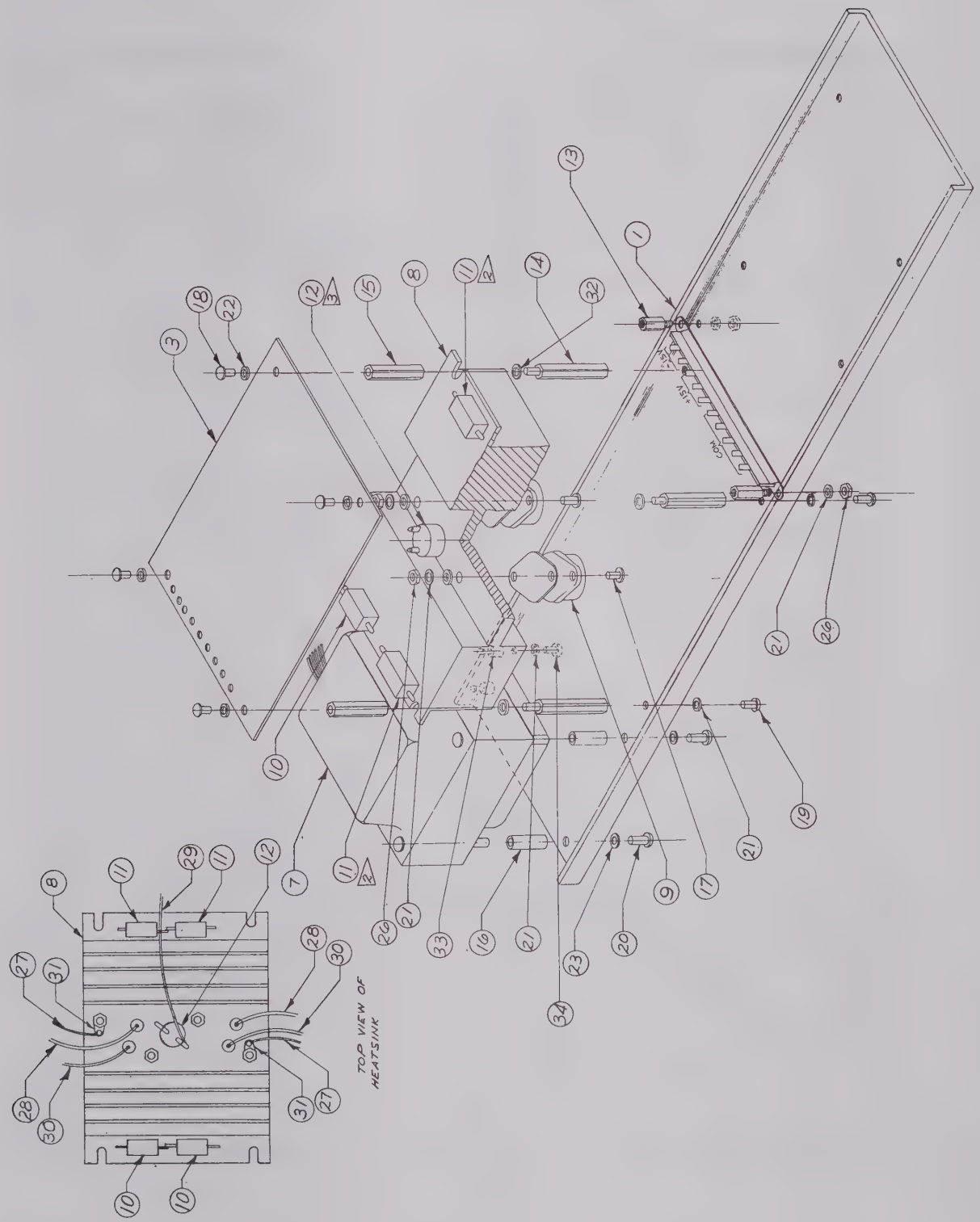


PICOAMMETER 930A ASSEMBLY
DWG. 2



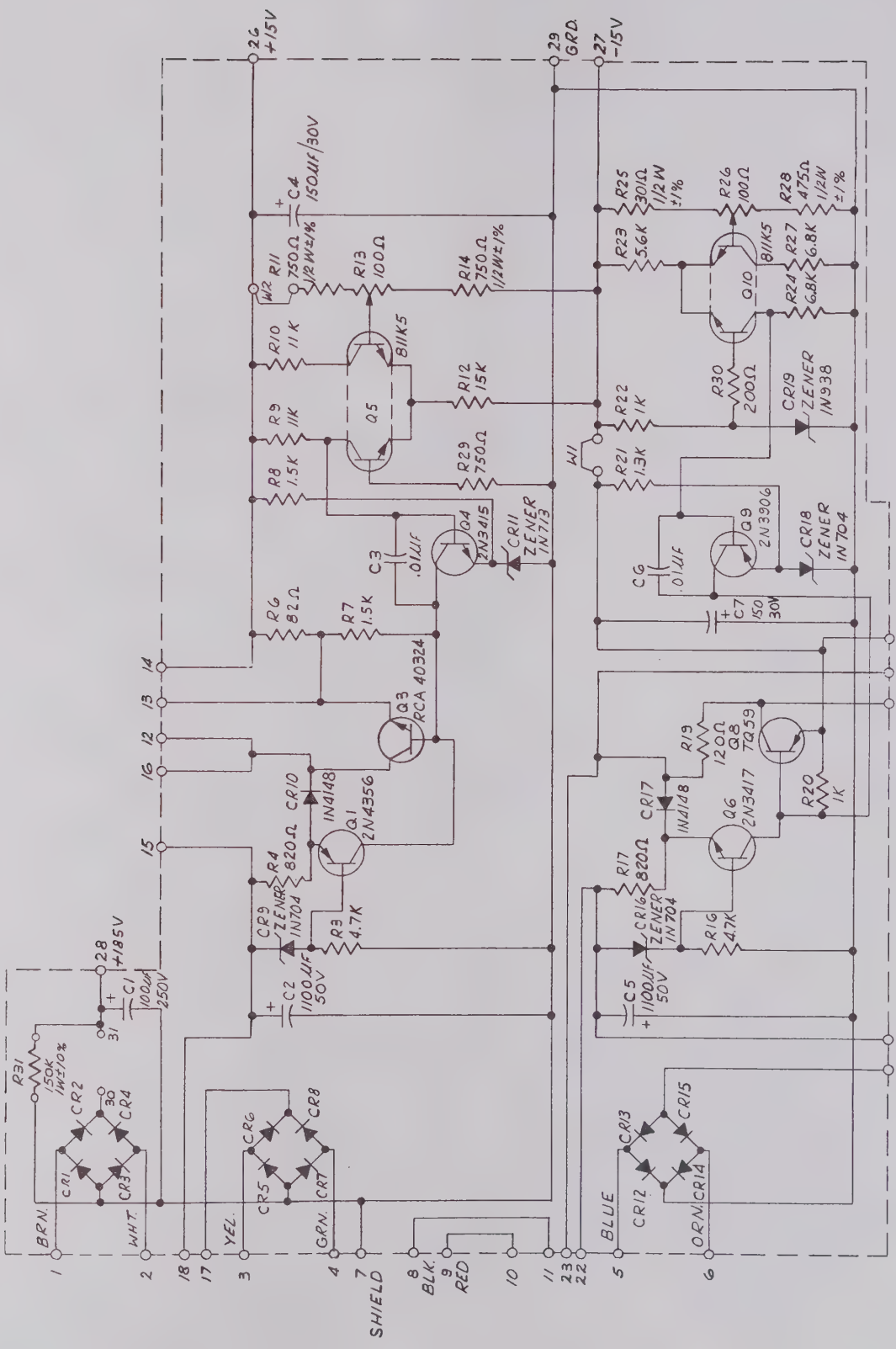
POWER SUPPLY, PS-1, SCHEMATIC
DWG. 3

EG&G DWG. NO. PC-2065-B

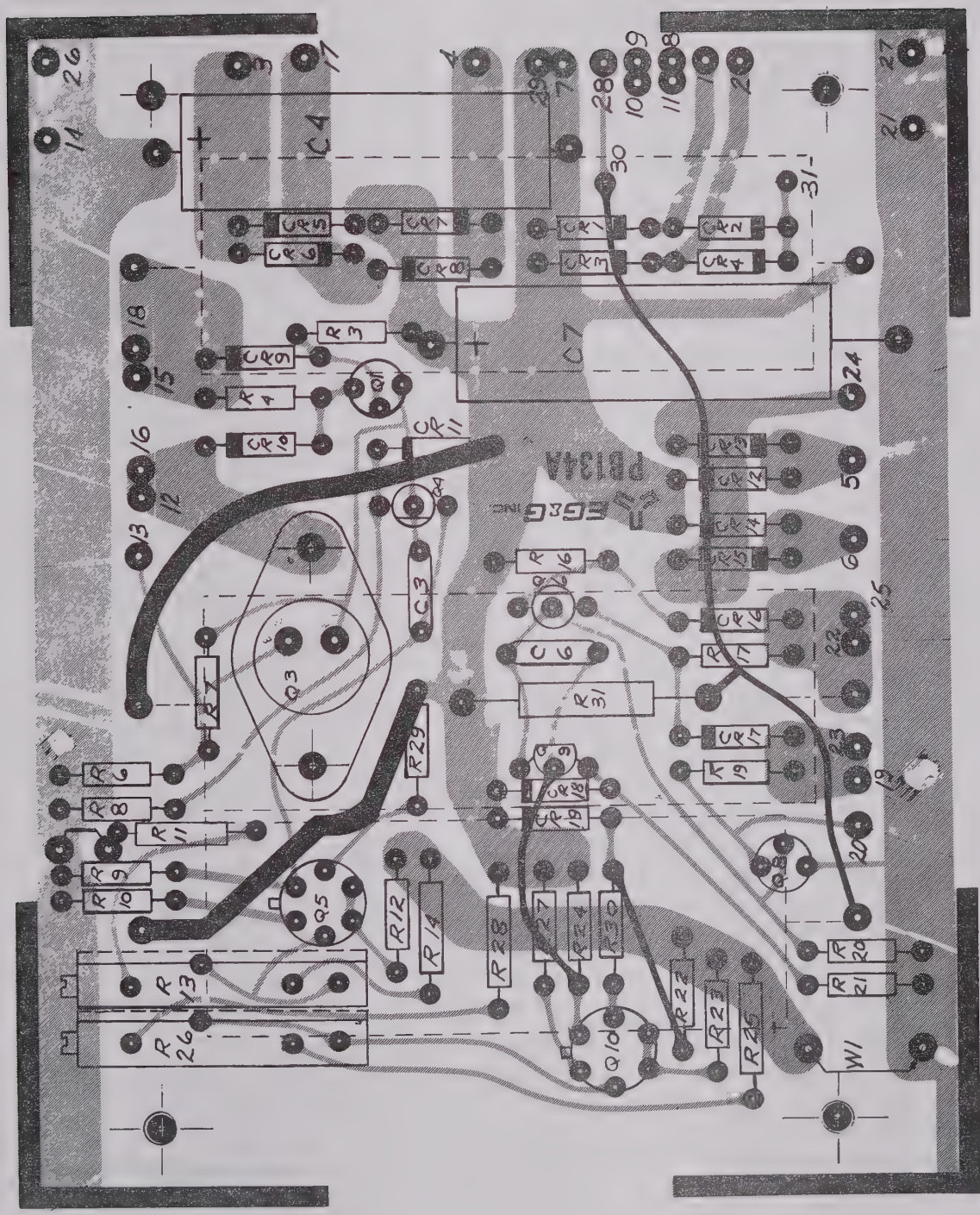


EG&G DWG. NO. PD-1023-F

POWER SUPPLY, PS-1, ASSEMBLY DWG. 4

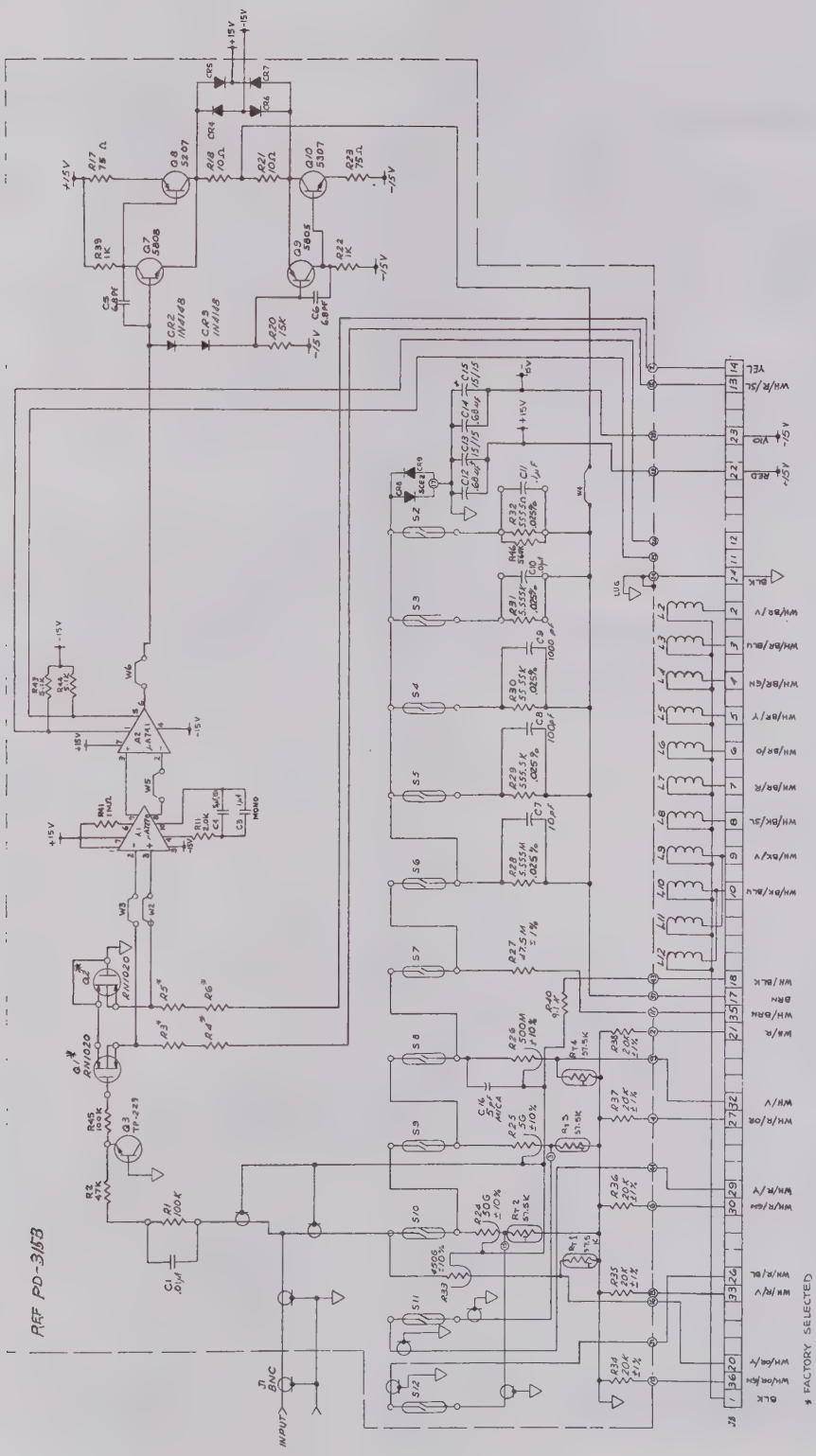


POWER SUPPLY (PS-1) REGULATOR SCHEMATIC EG&G DWG. NO. PC-3043-A
DWG. 5



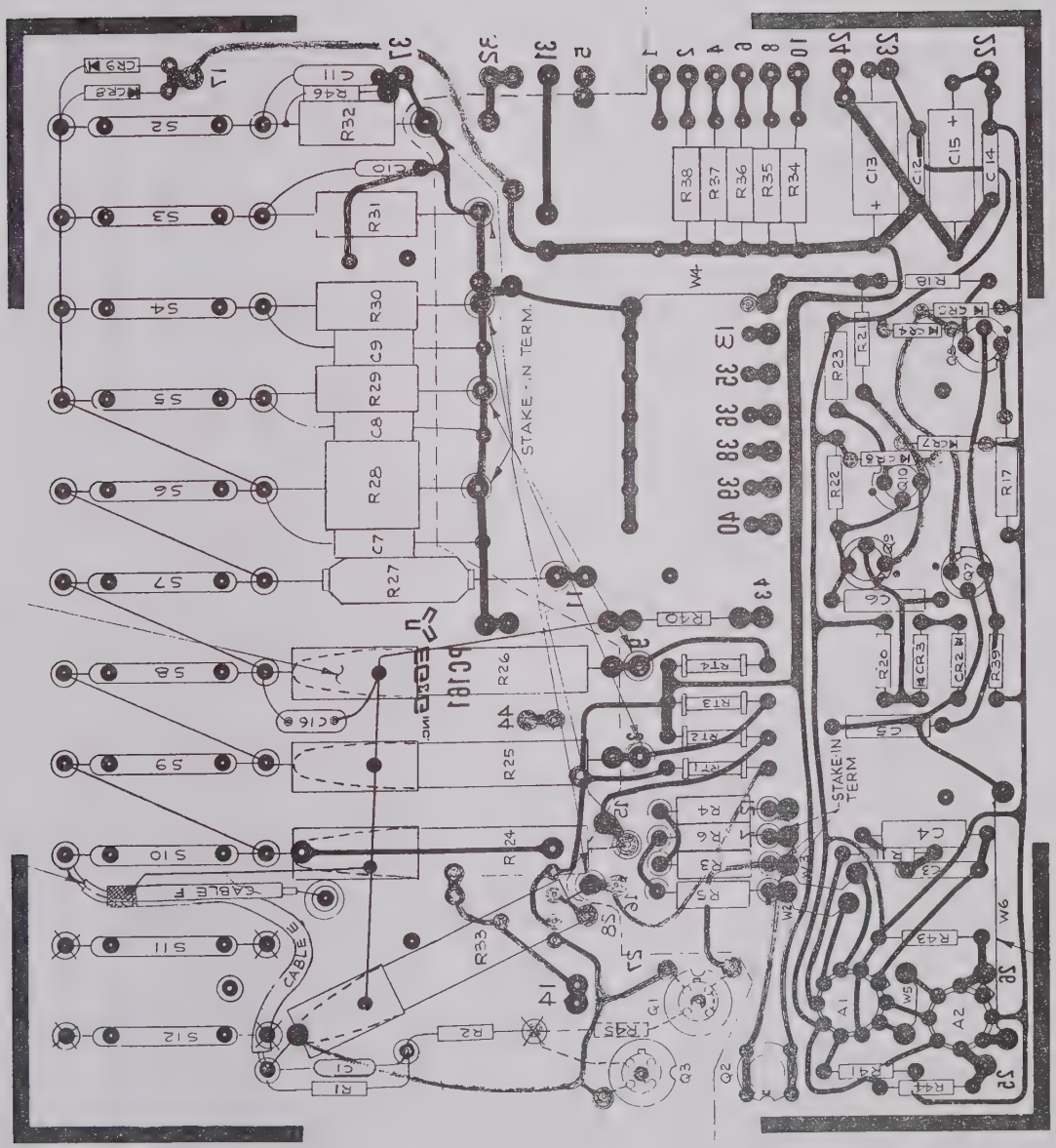
EG&G DWG. NO. PC-3043-A

POWER SUPPLY (PS-1) REGULATOR ASSEMBLY
DWG. 6



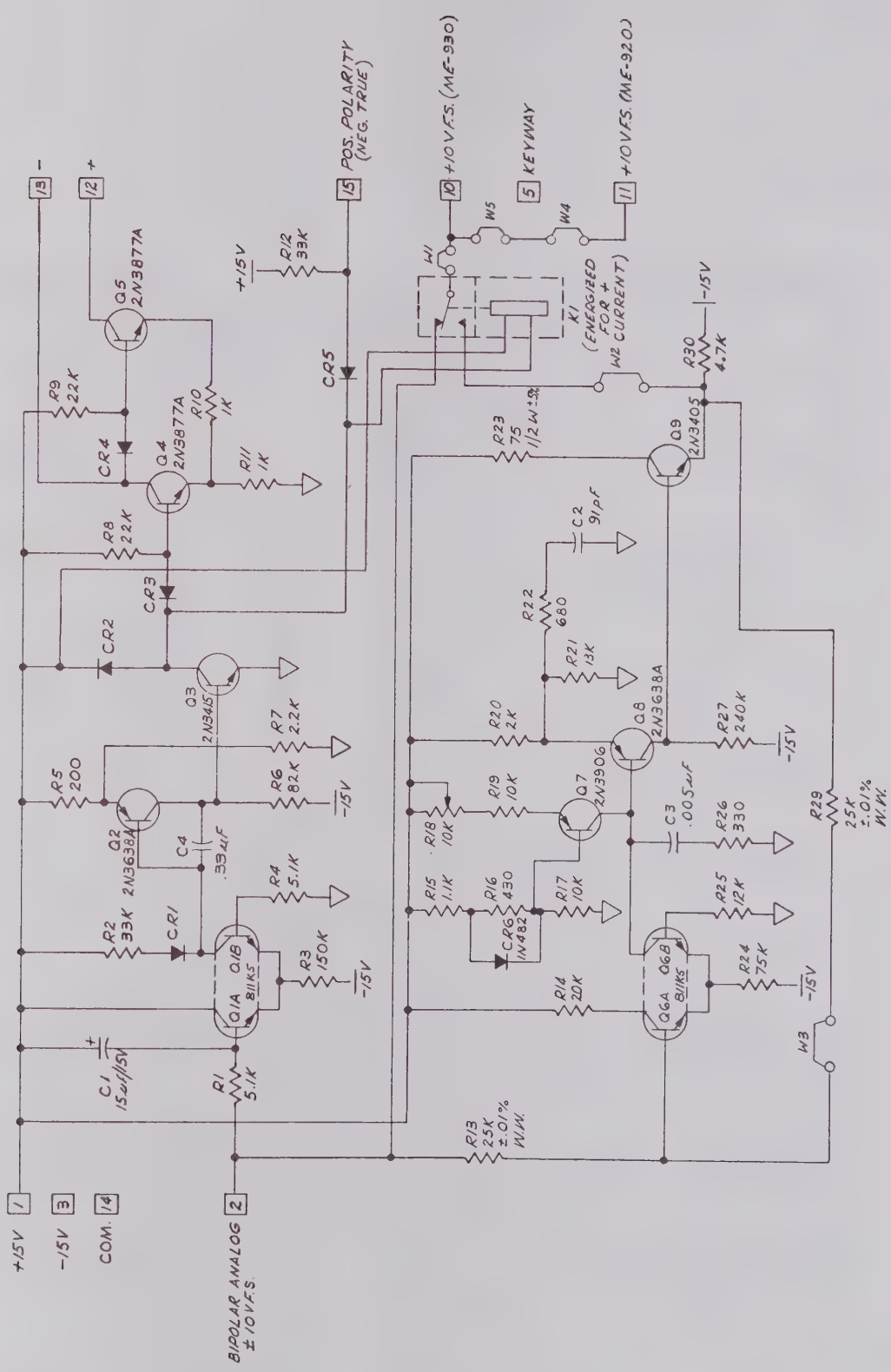
FEEDBACK SCHEMATIC
DWG. 7

EG&G DWG. NO. PD-2113-A



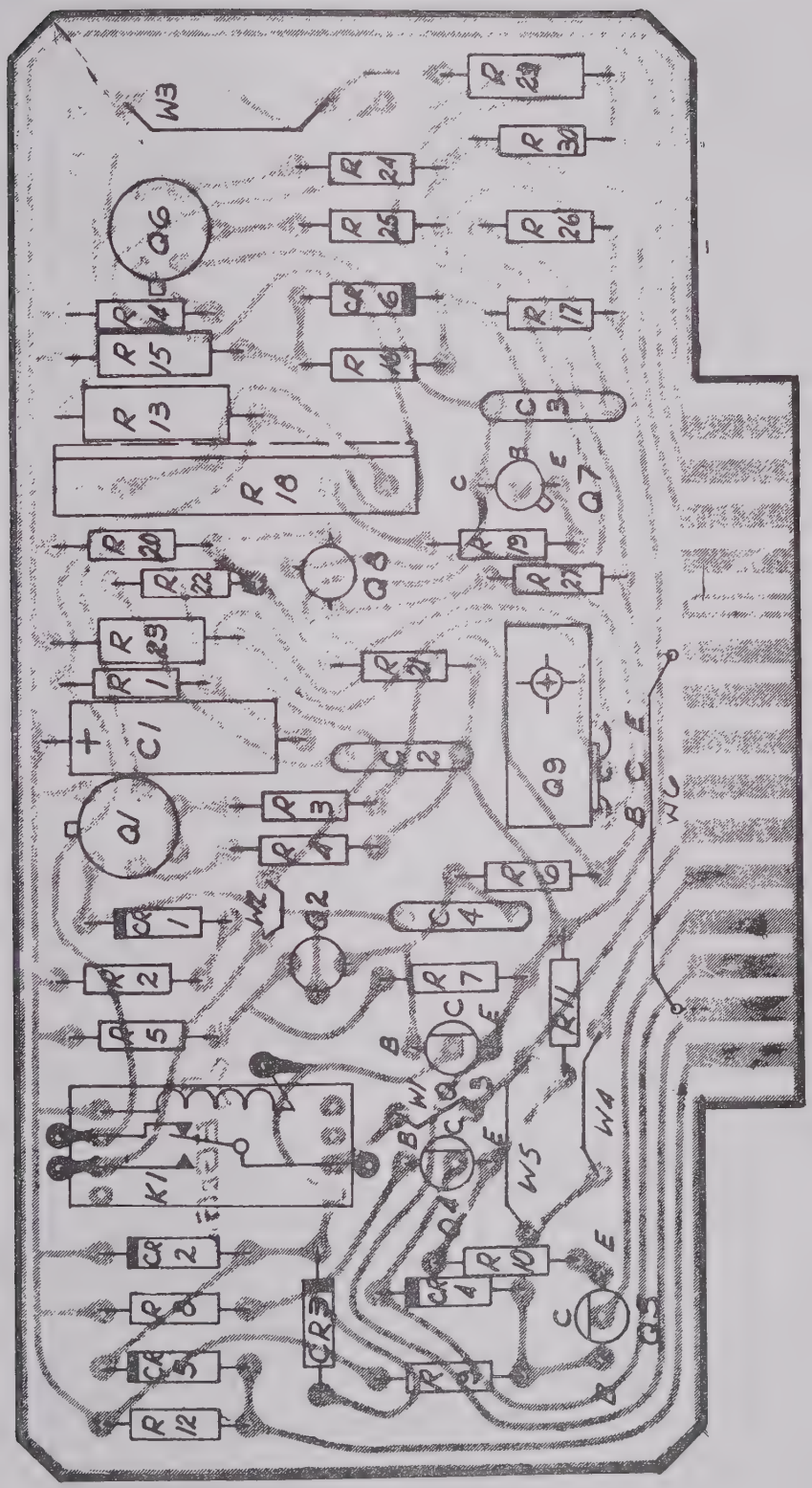
EG&G DWG. NO. PD-3153

FEEDBACK ASSEMBLY
DWG. 8



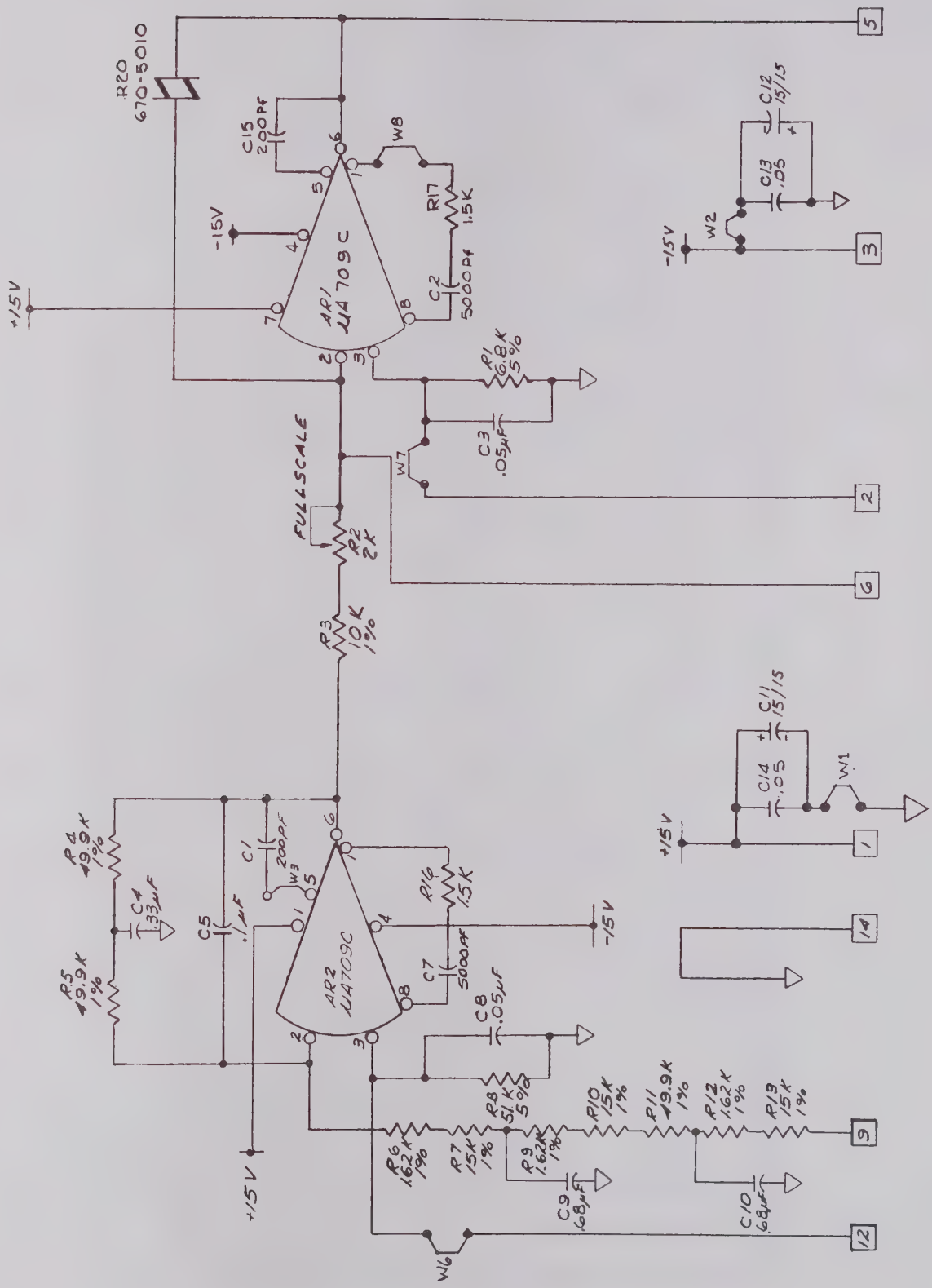
ABSOLUTE VALUE SCHEMATIC
DWG. 9

EG&G DWG. NO. PC-3135



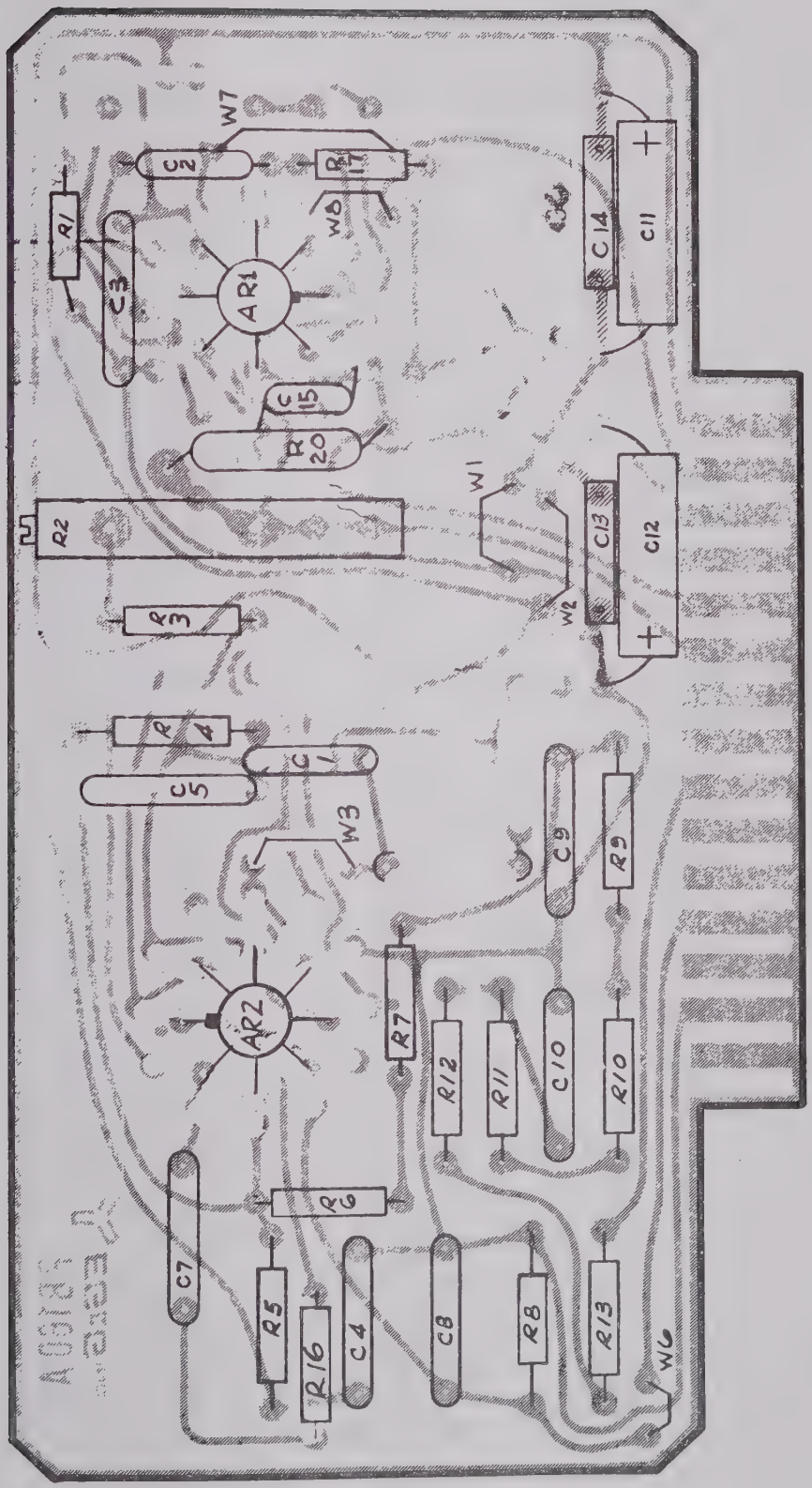
EG&G DWG. NO. PC-3135

ABSOLUTE VALUE ASSEMBLY
DWG. 10



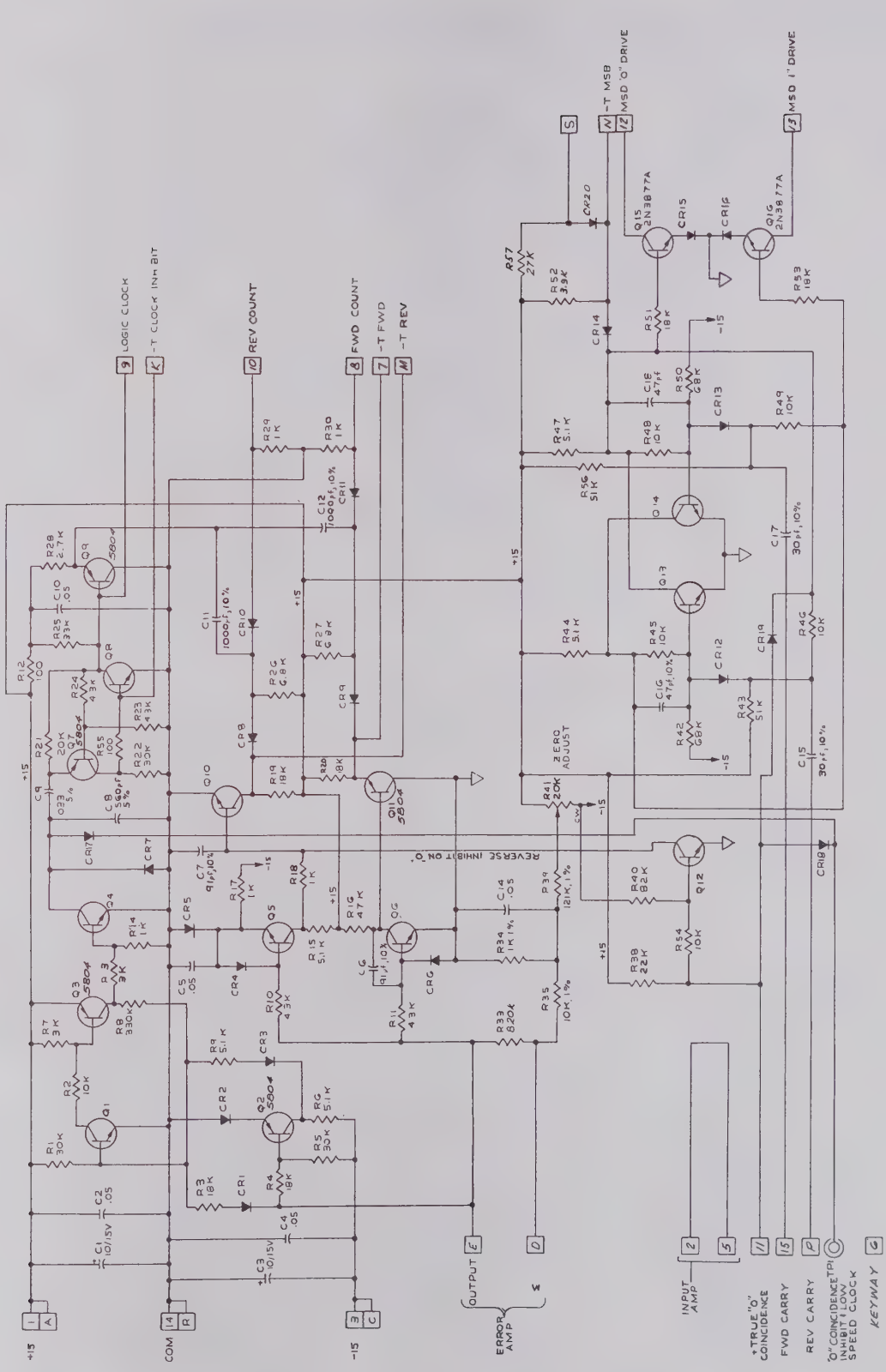
ADC DUAL OPERATIONAL AMPLIFIER SCHEMATIC
DWG. 11

EG&G DWG. NO. PC-3131



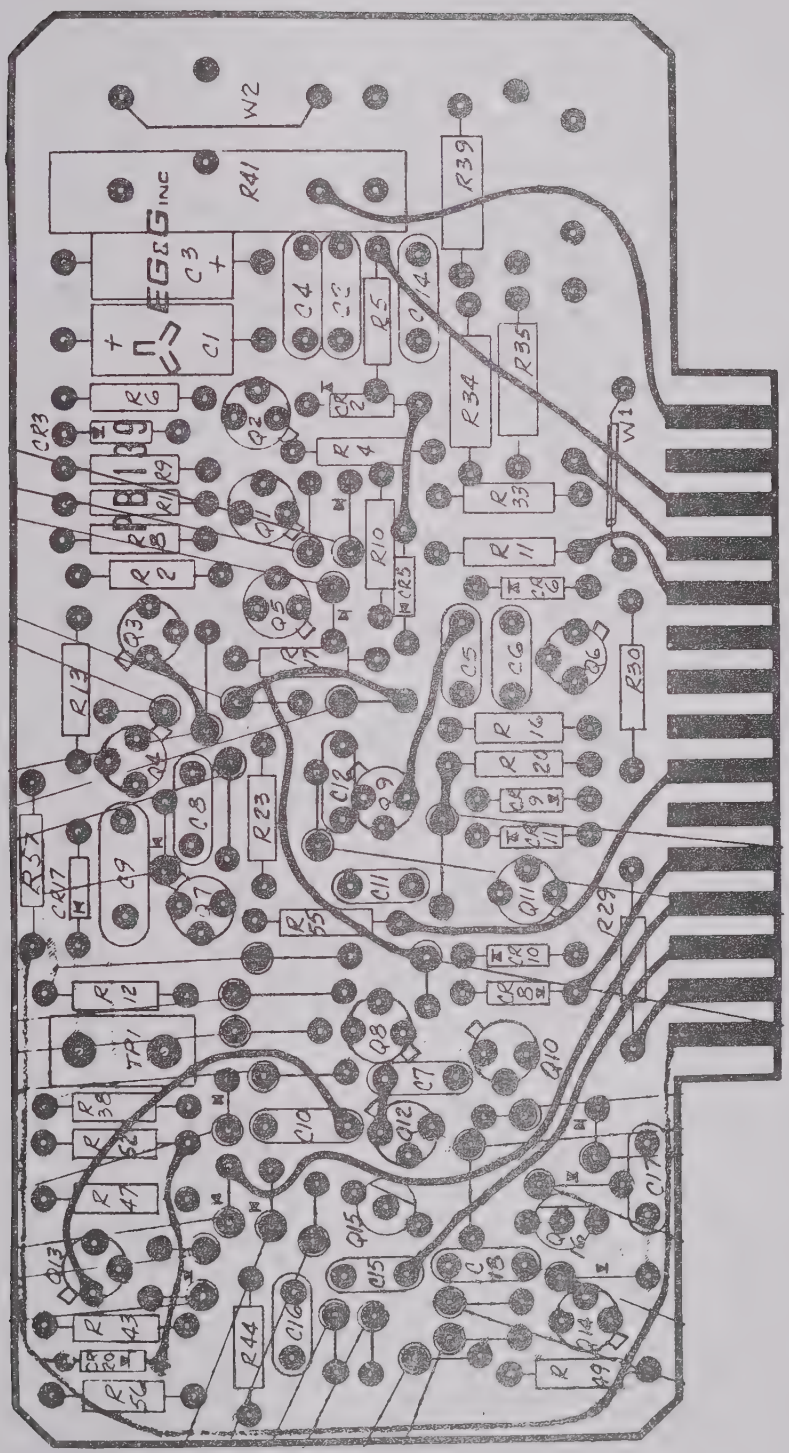
EG&G DWG. NO. PC-3131

ADC DUAL OPERATIONAL AMPLIFIER ASSEMBLY
DWG. 12



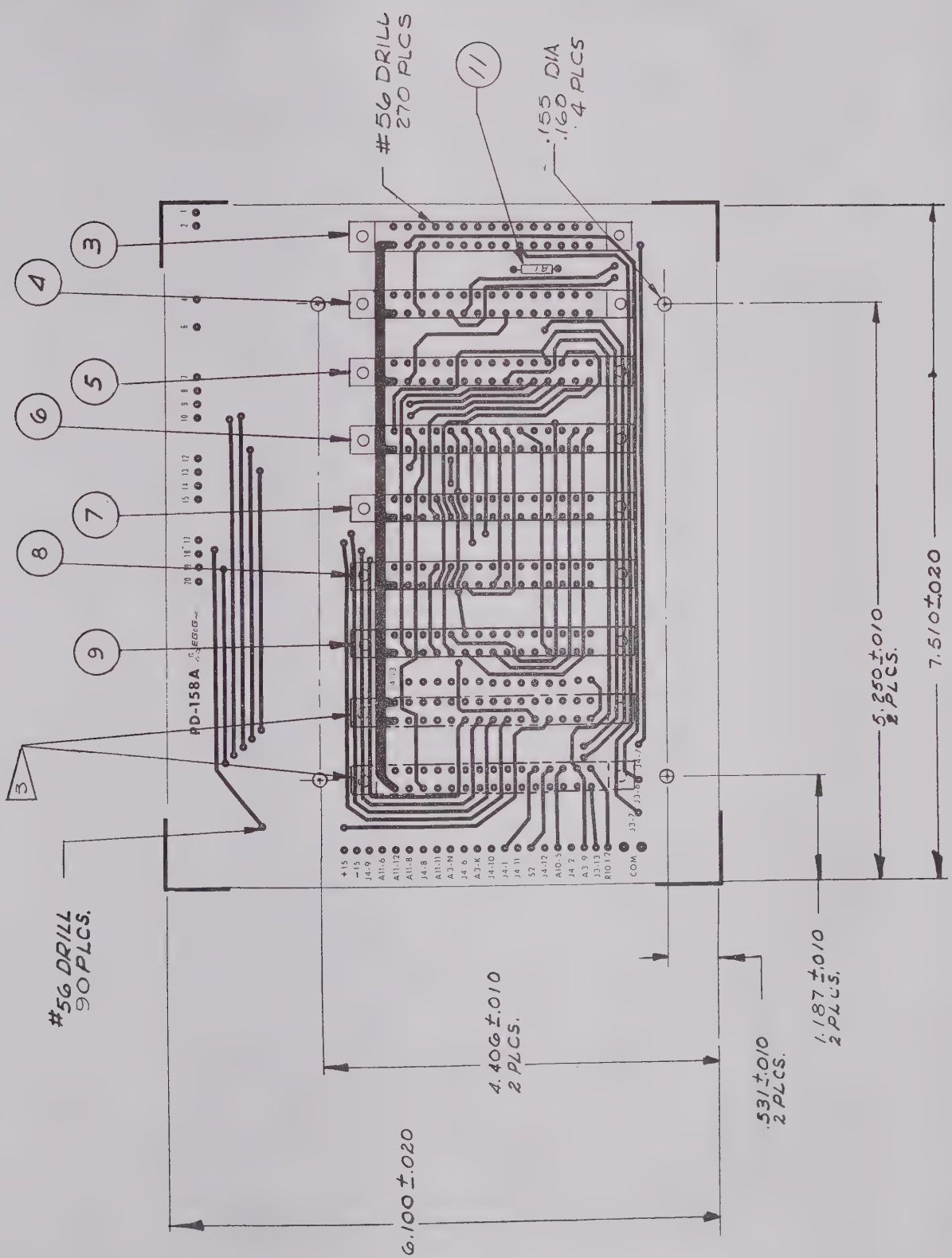
ADC CONTROL SCHEMATIC
DWG. 13

EG&G DWG. NO. PD-3134



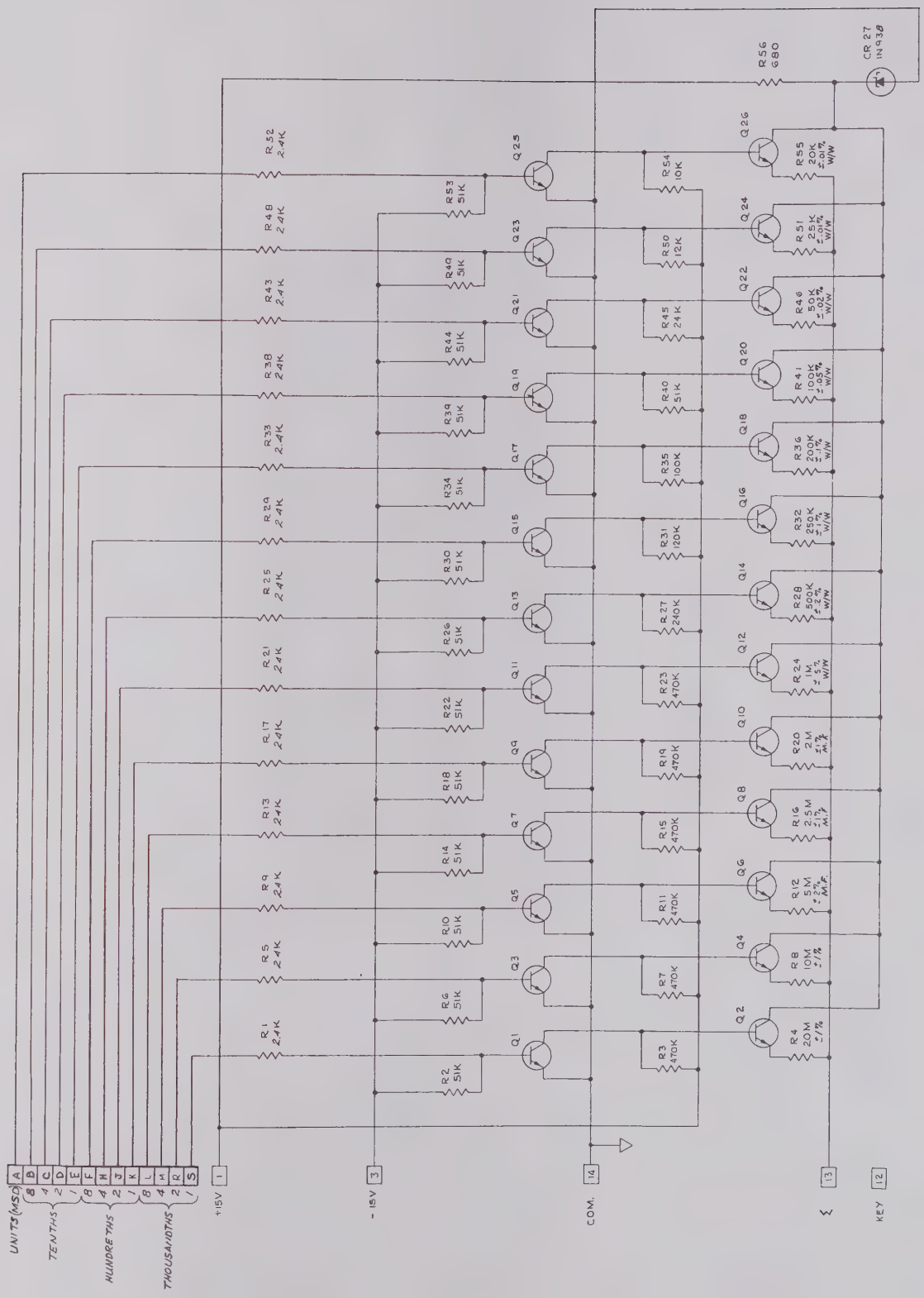
EG&G DWG. NO. PC-3134

ADC CONTROL ASSEMBLY
DWG. 14

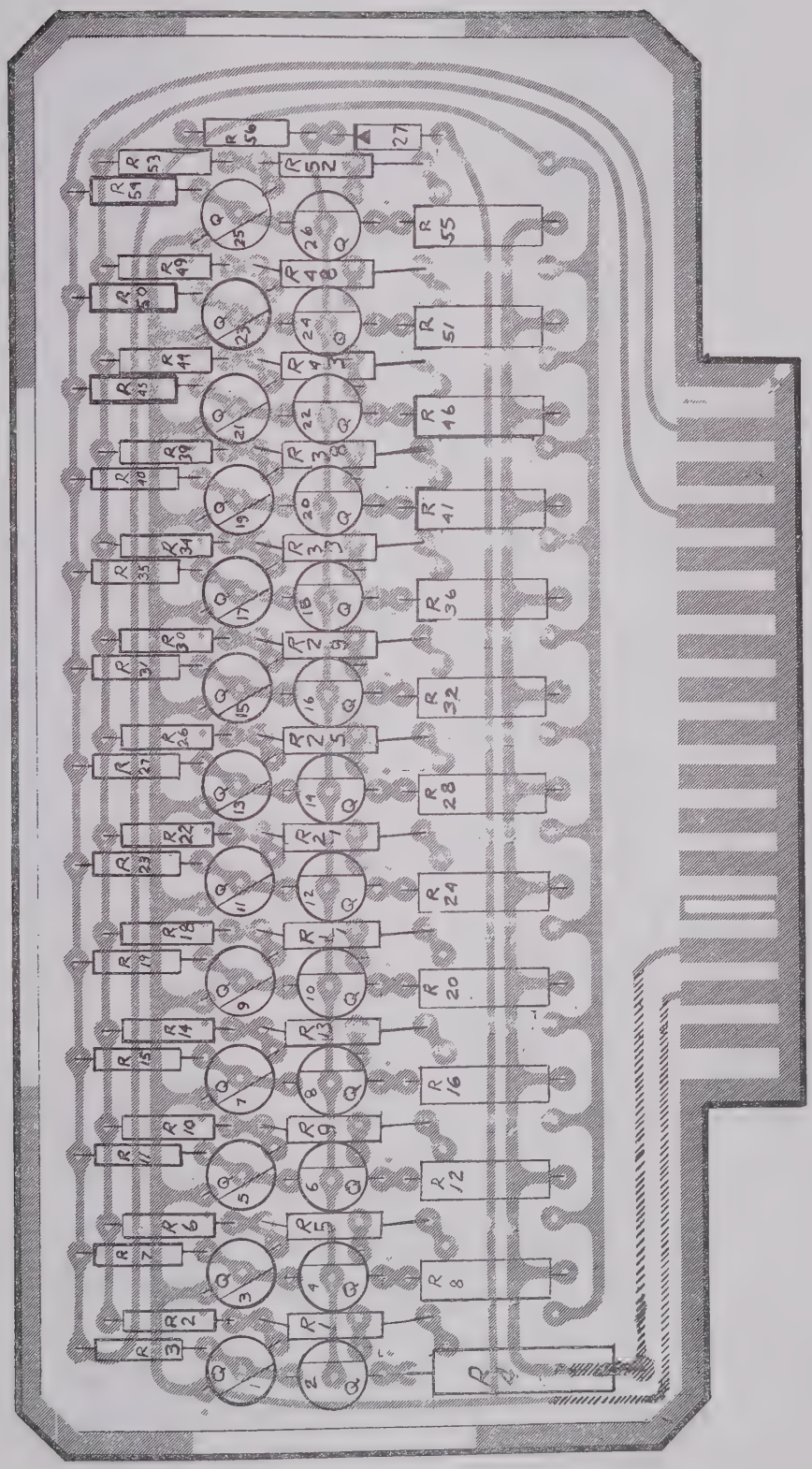


EG&G DWG. NO. PC-3128

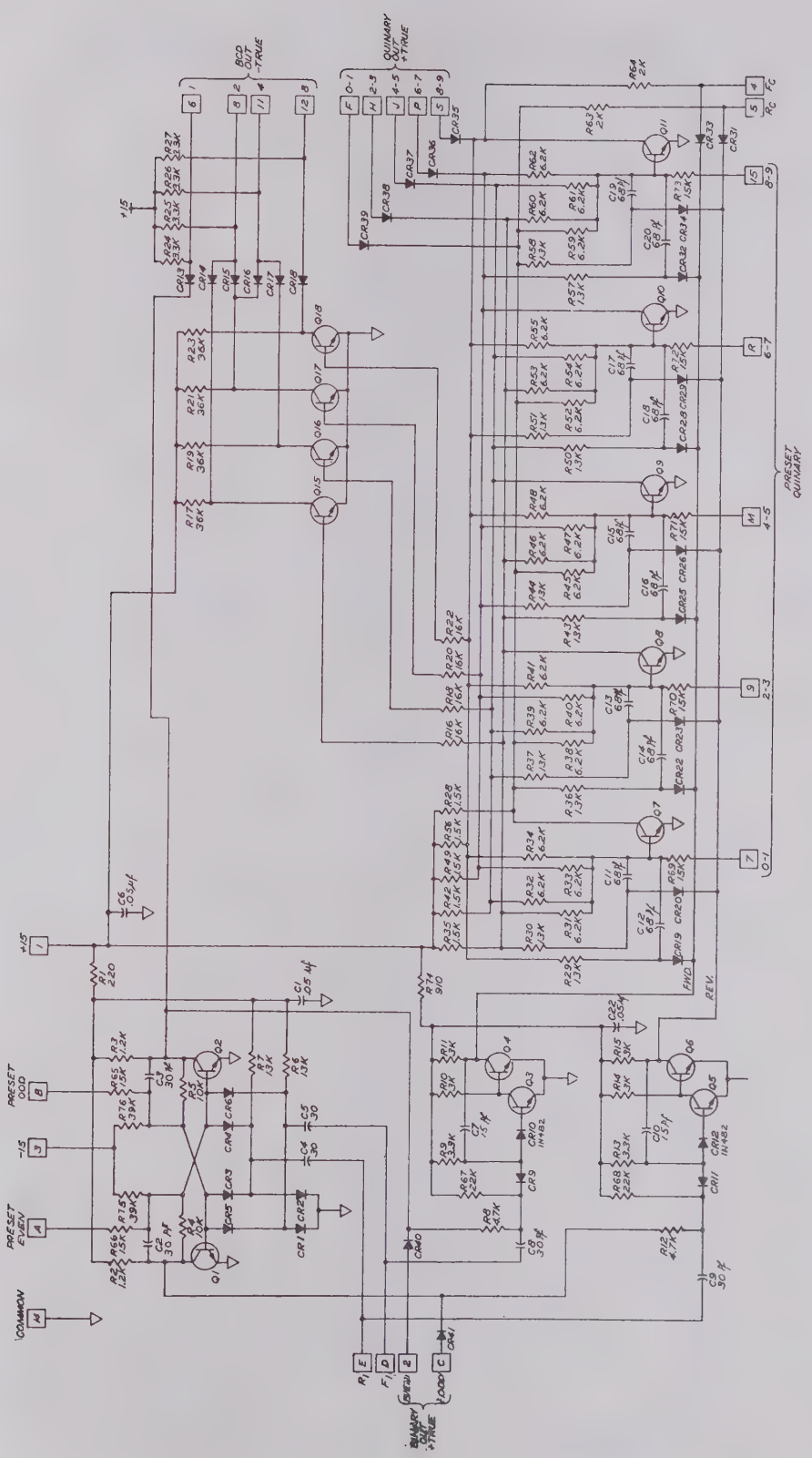
ADC INTERCONNECT ASSEMBLY
DWG. 15



DIGITAL-TO-ANALOG CONVERTER (13-BIT) SCHEMATIC EG&G DWG. NO. PE-3007-D
DWG. 16

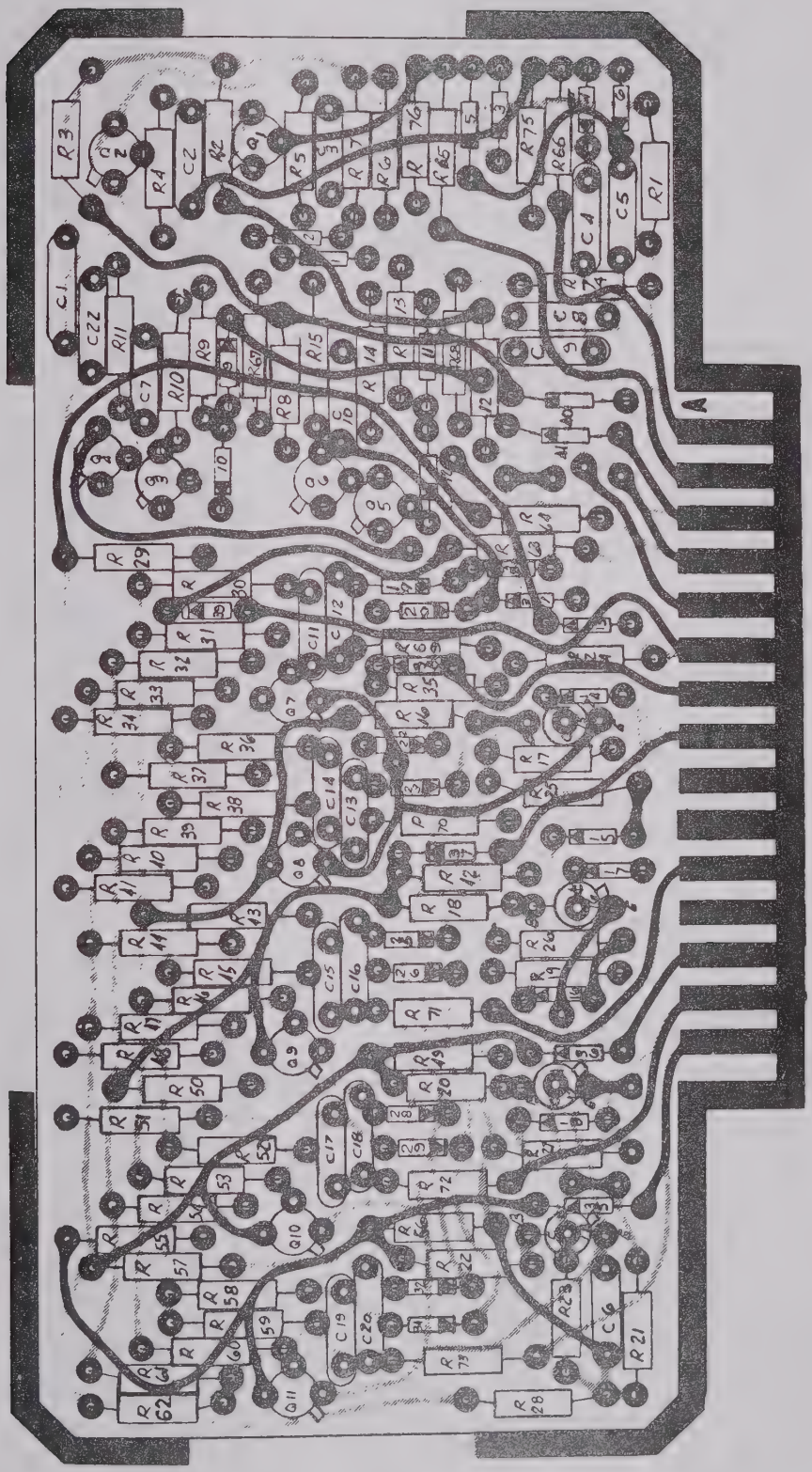


EG&G DWG. NO. PC-3007-D DIGITAL-TO-ANALOG CONVERTER (13-BIT) ASSEMBLY
DWG. 17



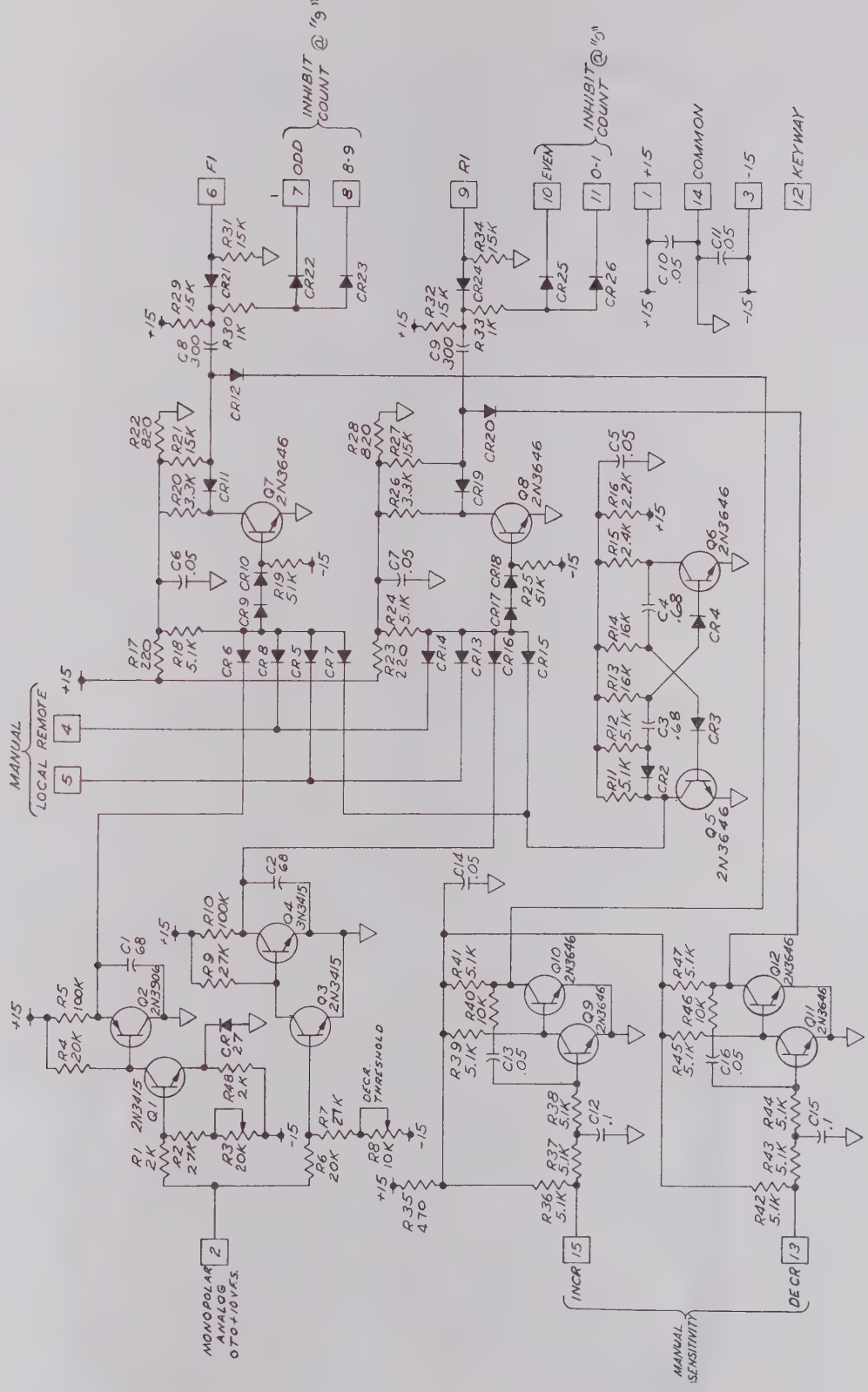
FWD.-REV. DECIMAL COUNTING UNIT SCHEMATIC
DWG. 18

EG&G DWG. NO. PD-3078-B



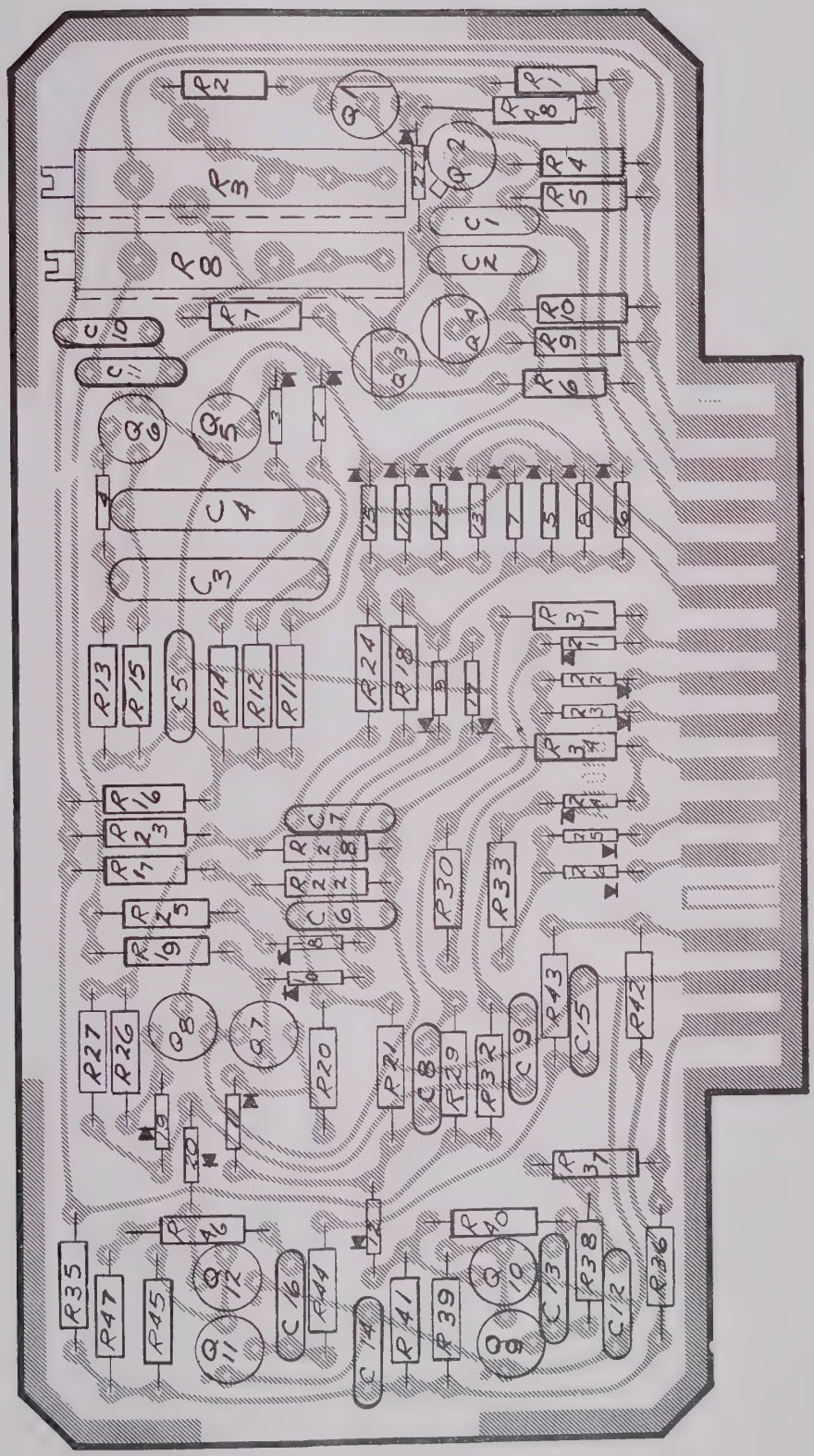
EG&G DWG. NO. PC-3078-B

FWD.-REV. DECIMAL COUNTING UNIT ASSEMBLY
DWG. 19



RANGE CONTROL SCHEMATIC
DWG. 20

EG&G DWG. NO. PC-3136-A

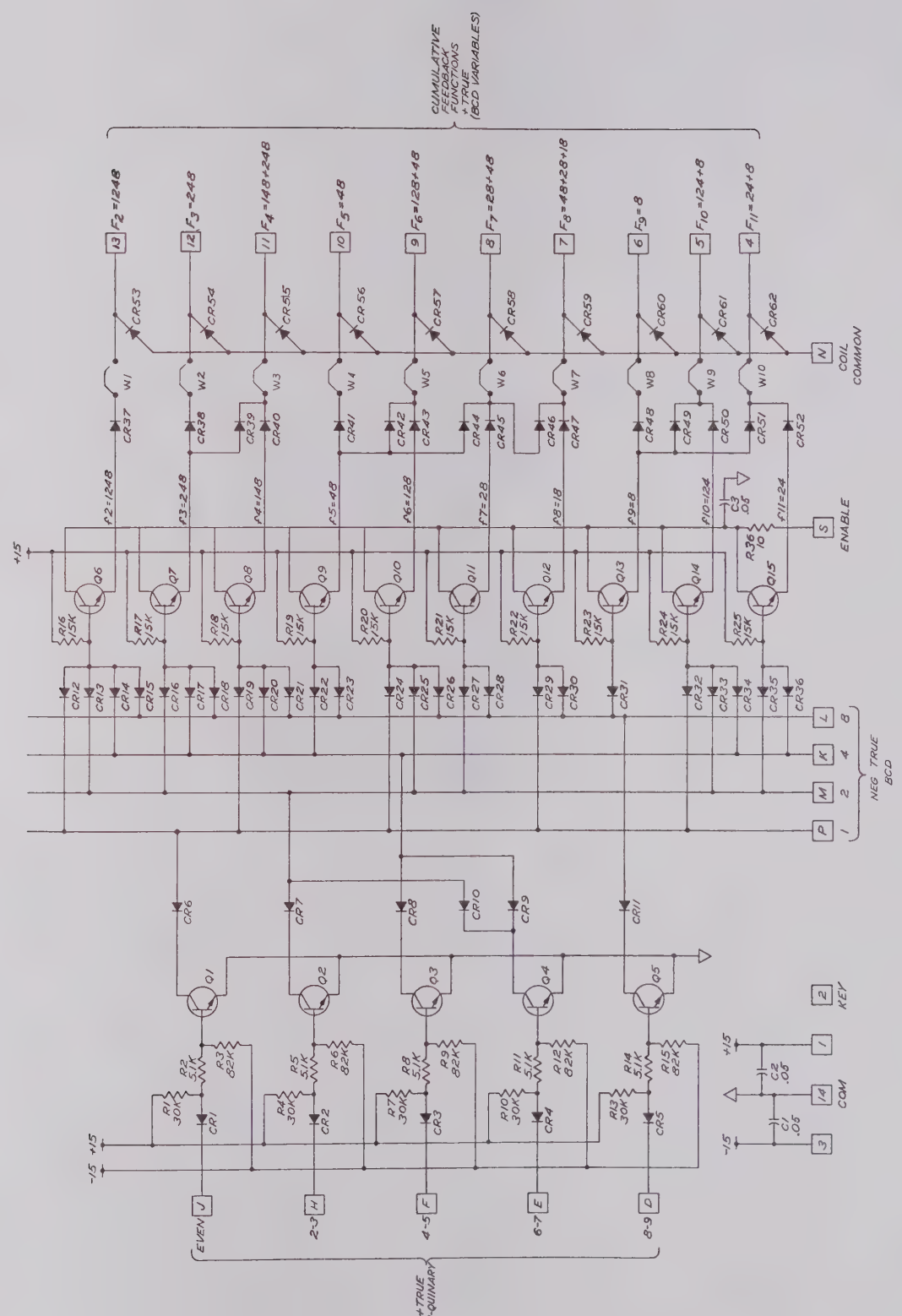


EG&G DWG. NO. PC-3136-A

RANGE CONTROL ASSEMBLY
DWG. 21

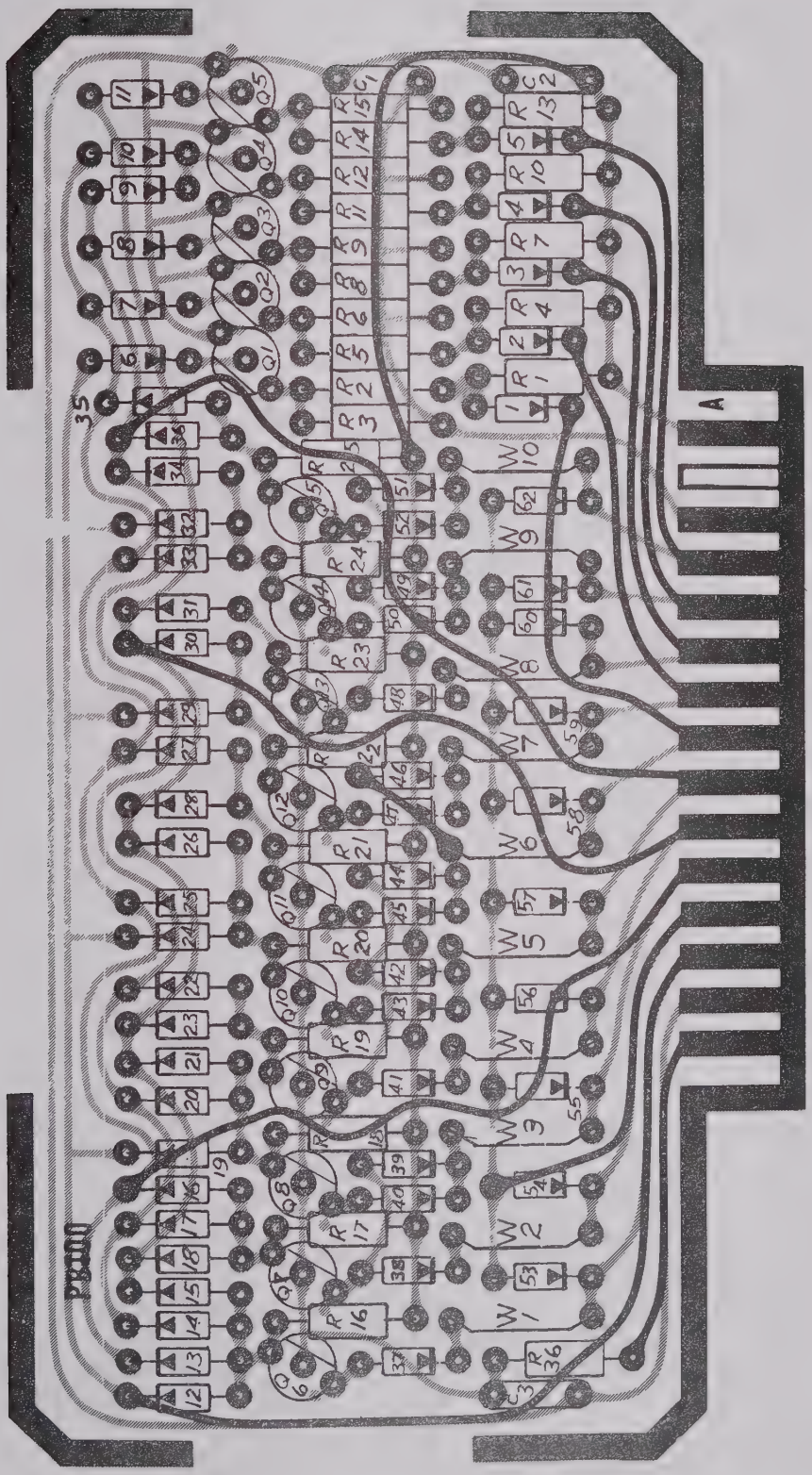
EG&G DWG. NO. PC-3121

RANGE CONTROL INTERCONNECT ASSEMBLY
DWG. 22



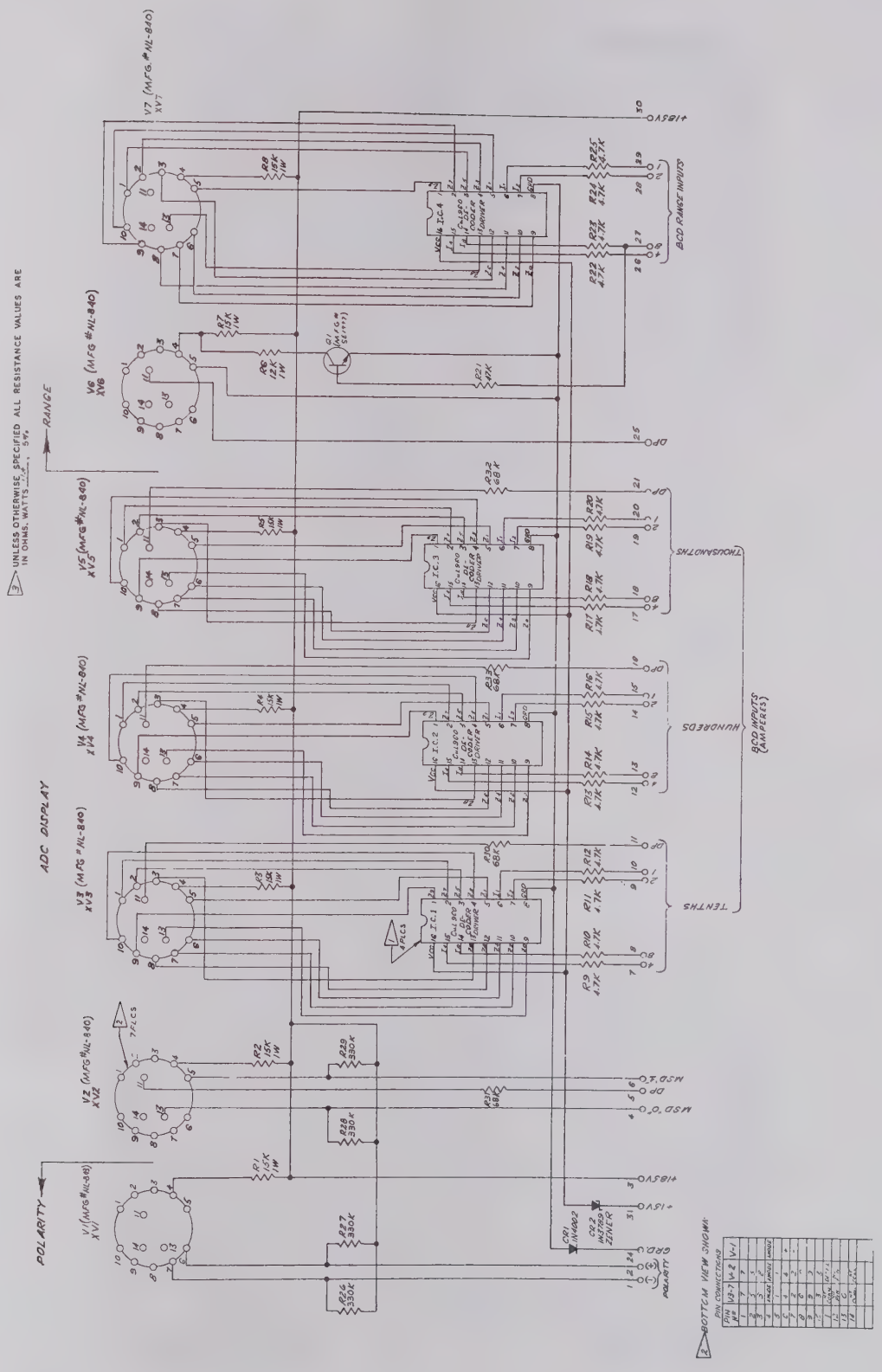
DECODER/DRIVER,ME-900, SCHEMATIC
DWG. 23

EG&G DWG. NO. PD-3000-B



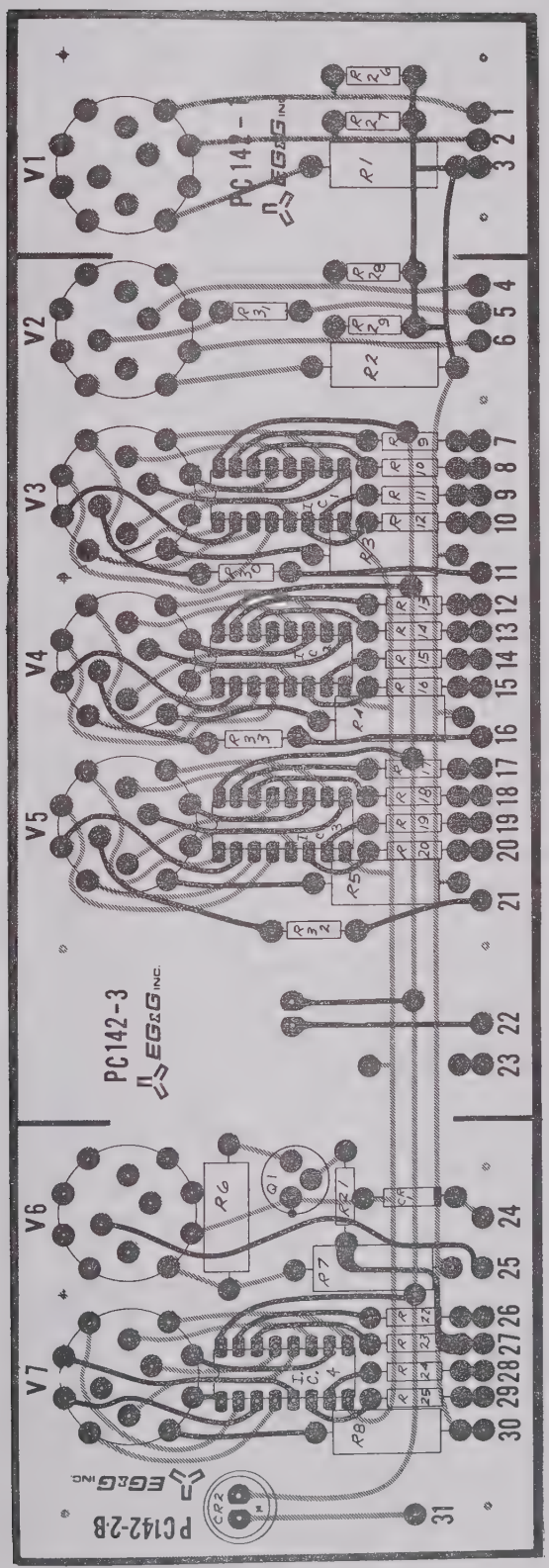
EG&G DWG NO. PD-3000-B

DECODER/DRIVER, ME-900, ASSEMBLY
DWG. 24



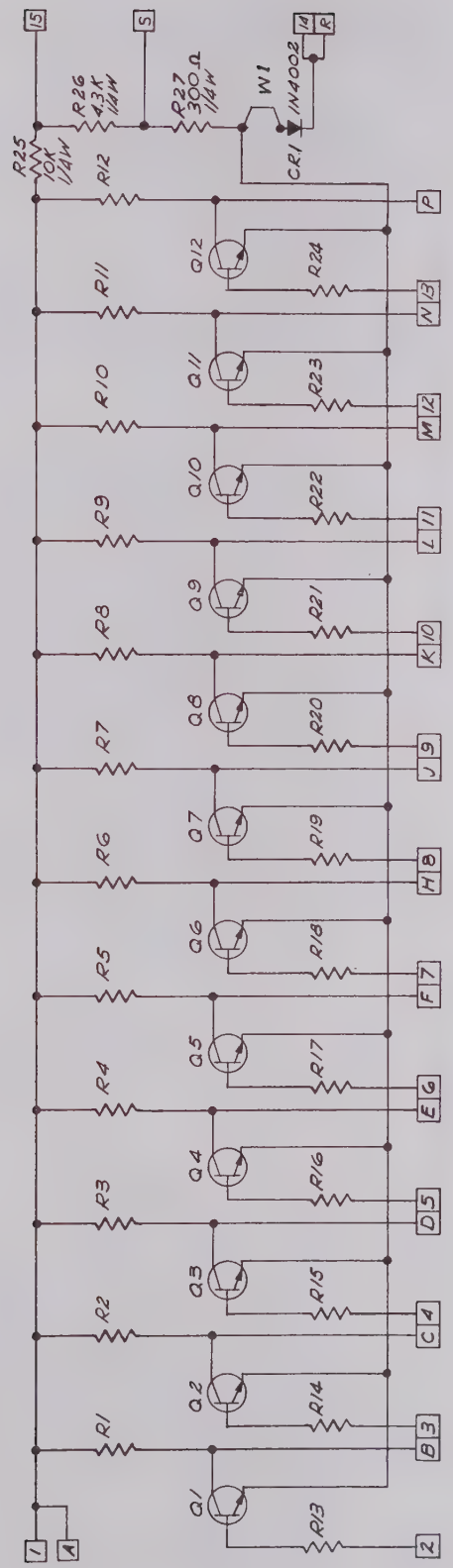
DIGITAL DISPLAY, PB-142, SCHEMATIC
DWG. 25

EG&G DWG. NO. PD-3084-D



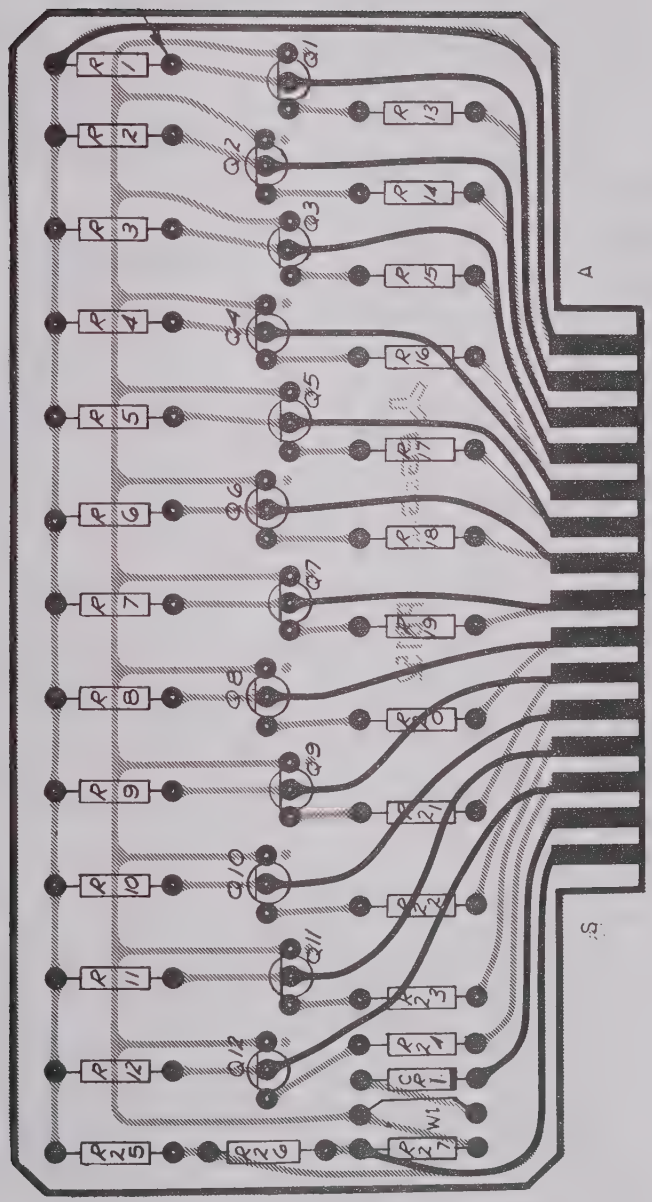
EG&G DWG. NO. PD-3084-D

DIGITAL DISPLAY, PB-142, ASSEMBLY DWG. 26



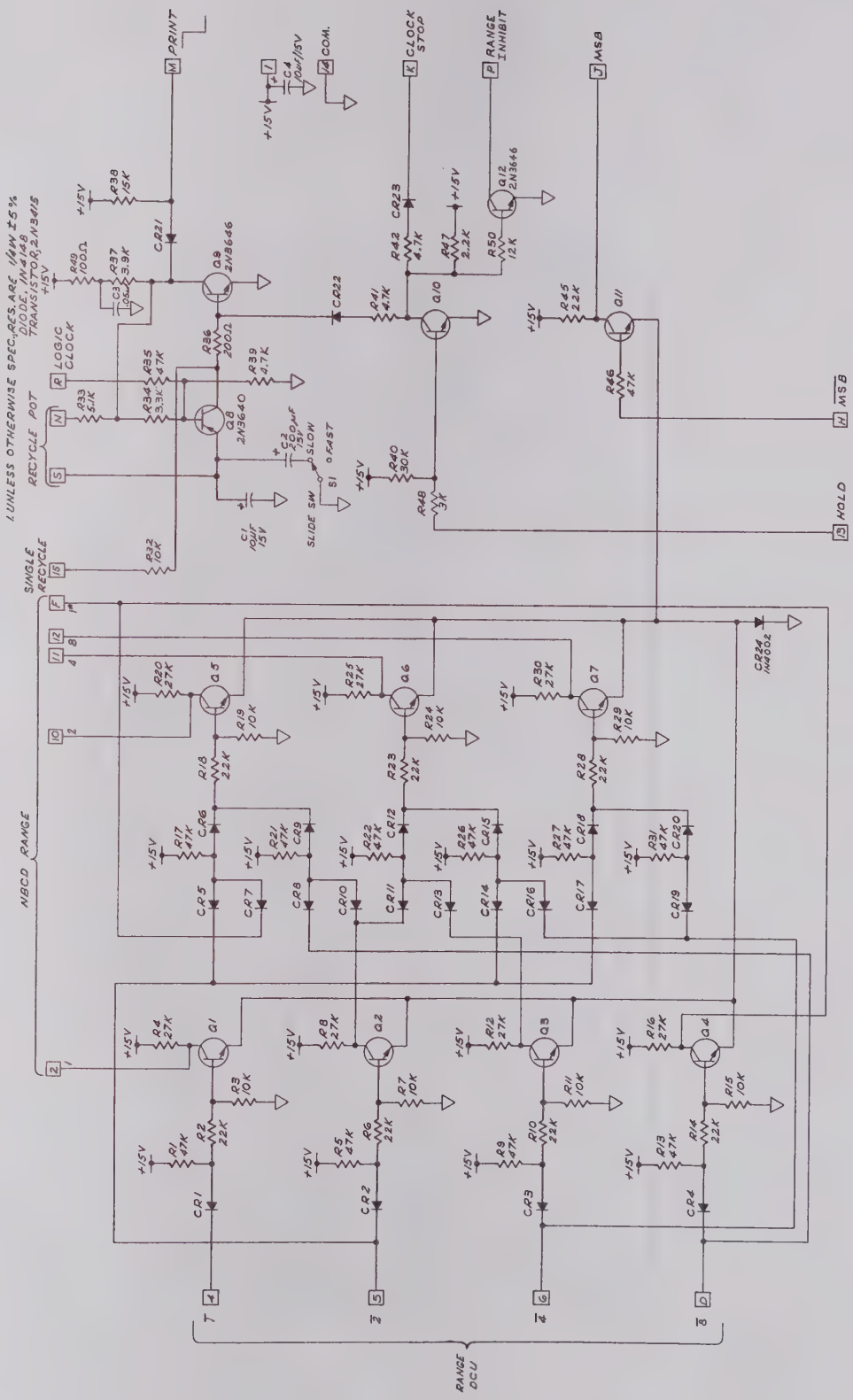
OPTION 01A, HEX D INVERTER SCHEMATIC
DWG. 27

EG&G DWG. NO. PC-3099

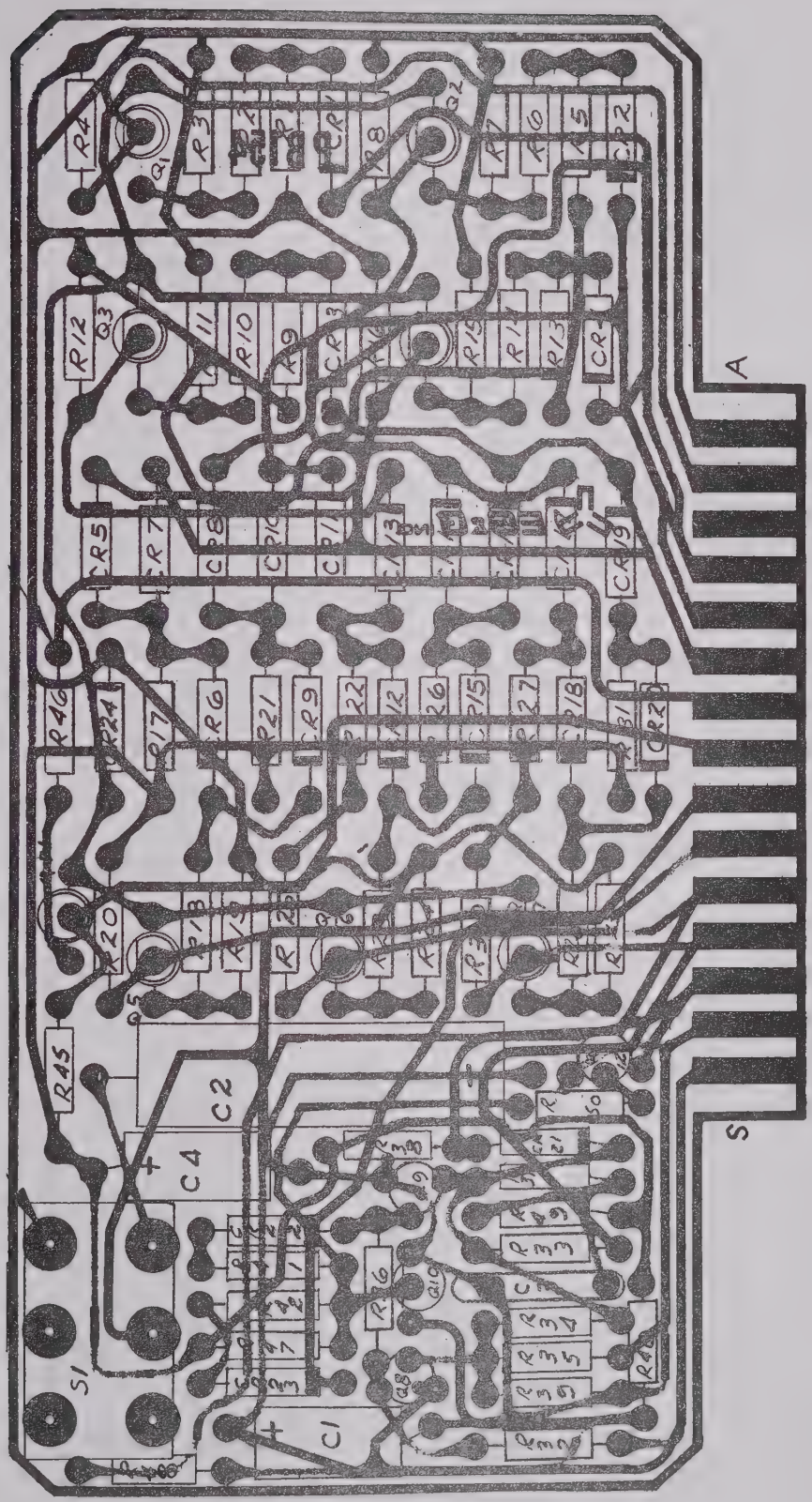


EG&G DWG NO. PC-3099

OPTION 01A, HEX D INVERTER ASSEMBLY
DWG. 28

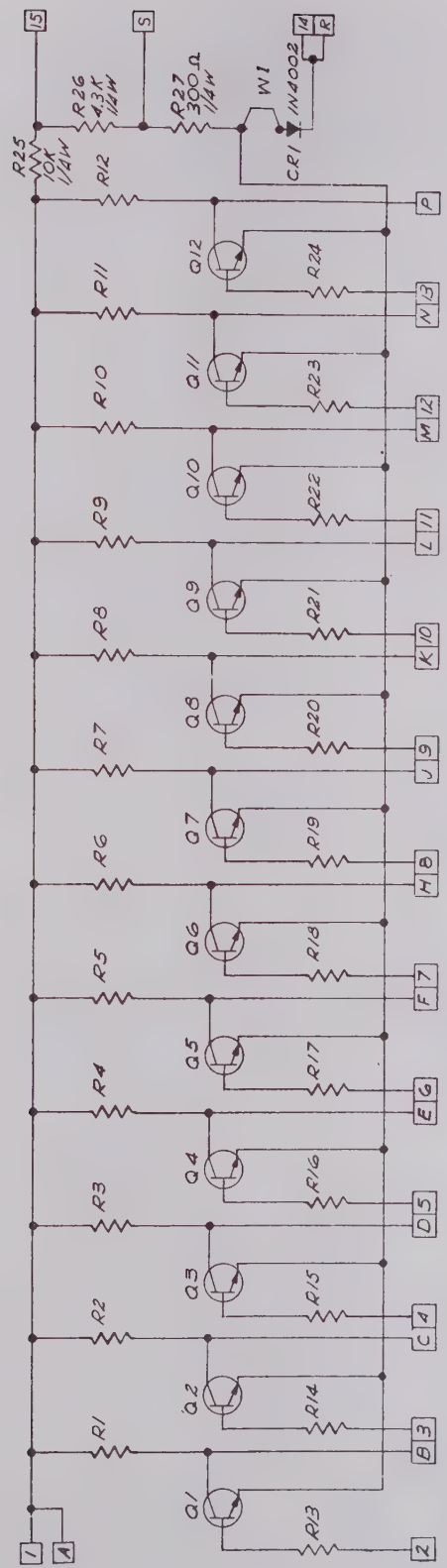


OPTION 01A, PRINT CONTROL AND RANGE DECODER SCHEM. EG&G DWG. NO. PD-3090-A DWG. 29



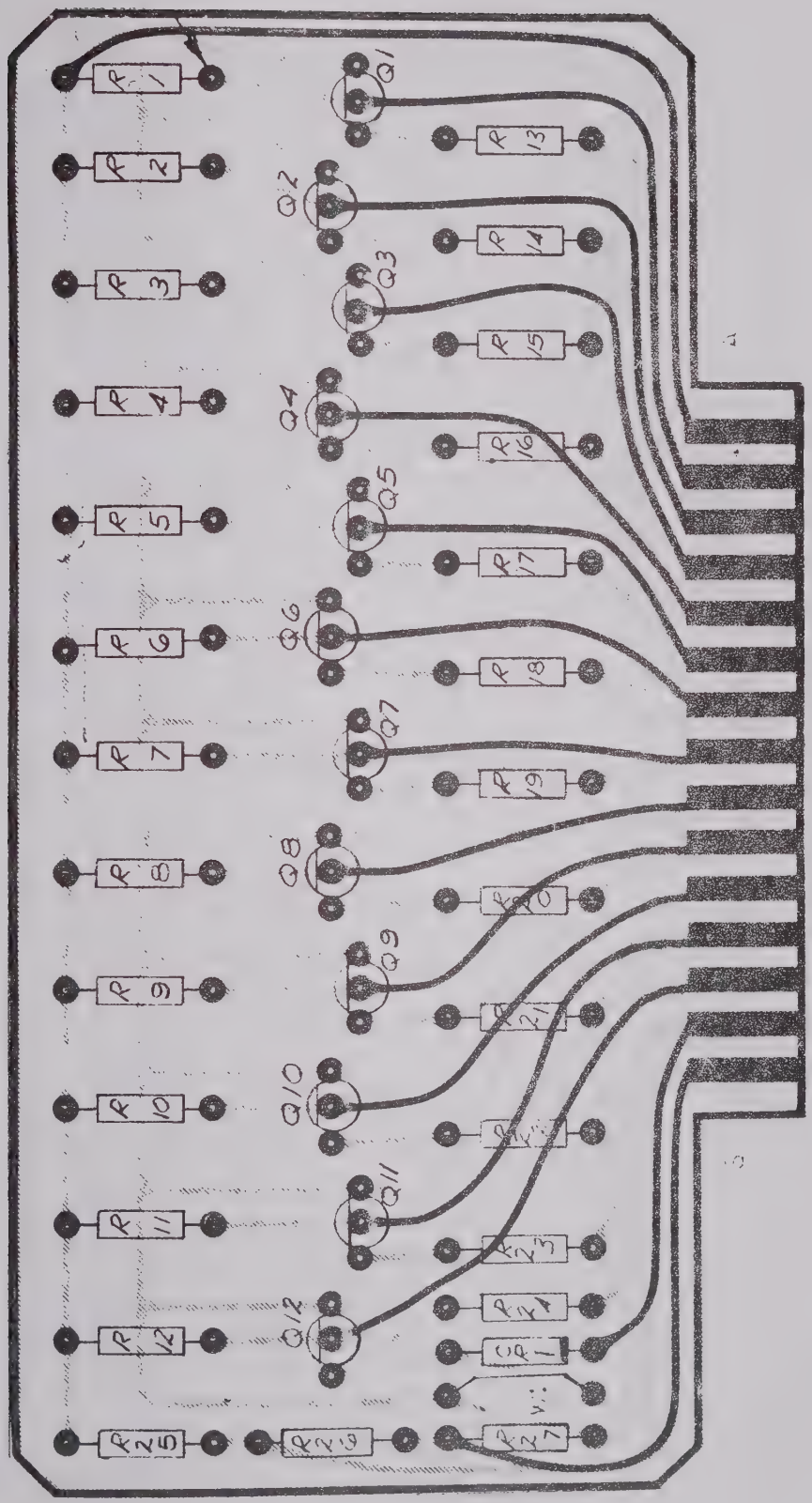
EG&G DWG. NO. PD-3090-A

OPTION 01A, PRINT CONTROL AND RANGE DECODER ASSEMBLY DWG. 30



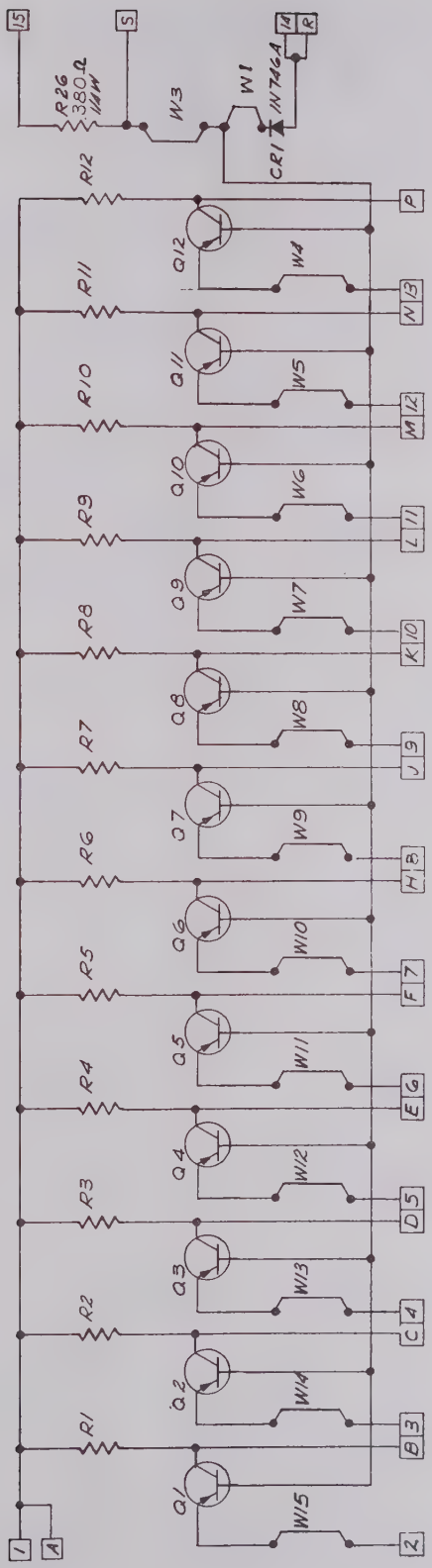
OPTION 01C, HEX D INVERTER SCHEMATIC
DWG. 31

EG&G DWG. NO. PC-3200



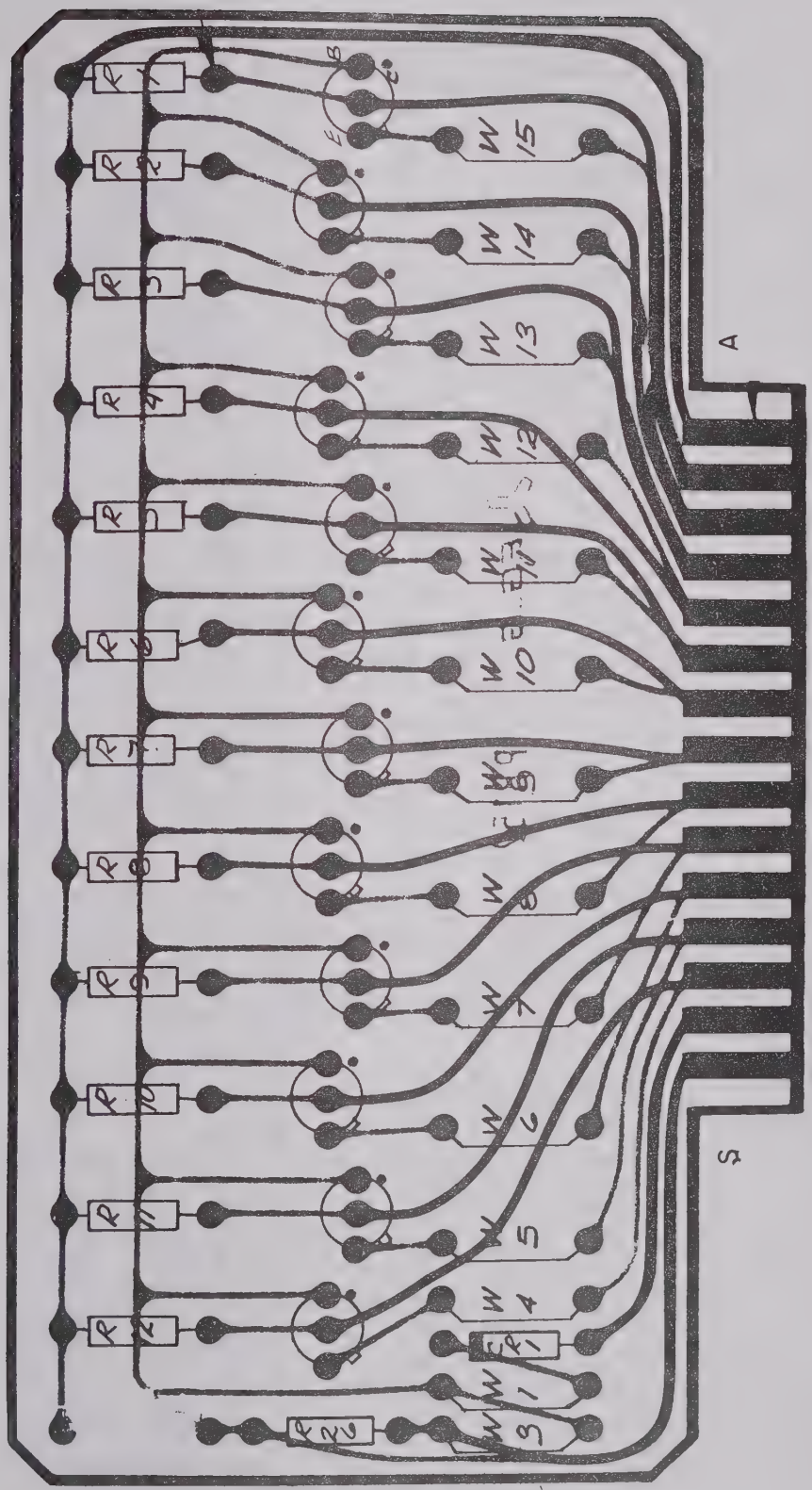
EG&G DWG NO. PC-3200

OPTION 01C, HEX D INVERTER ASSEMBLY
DWG. 32

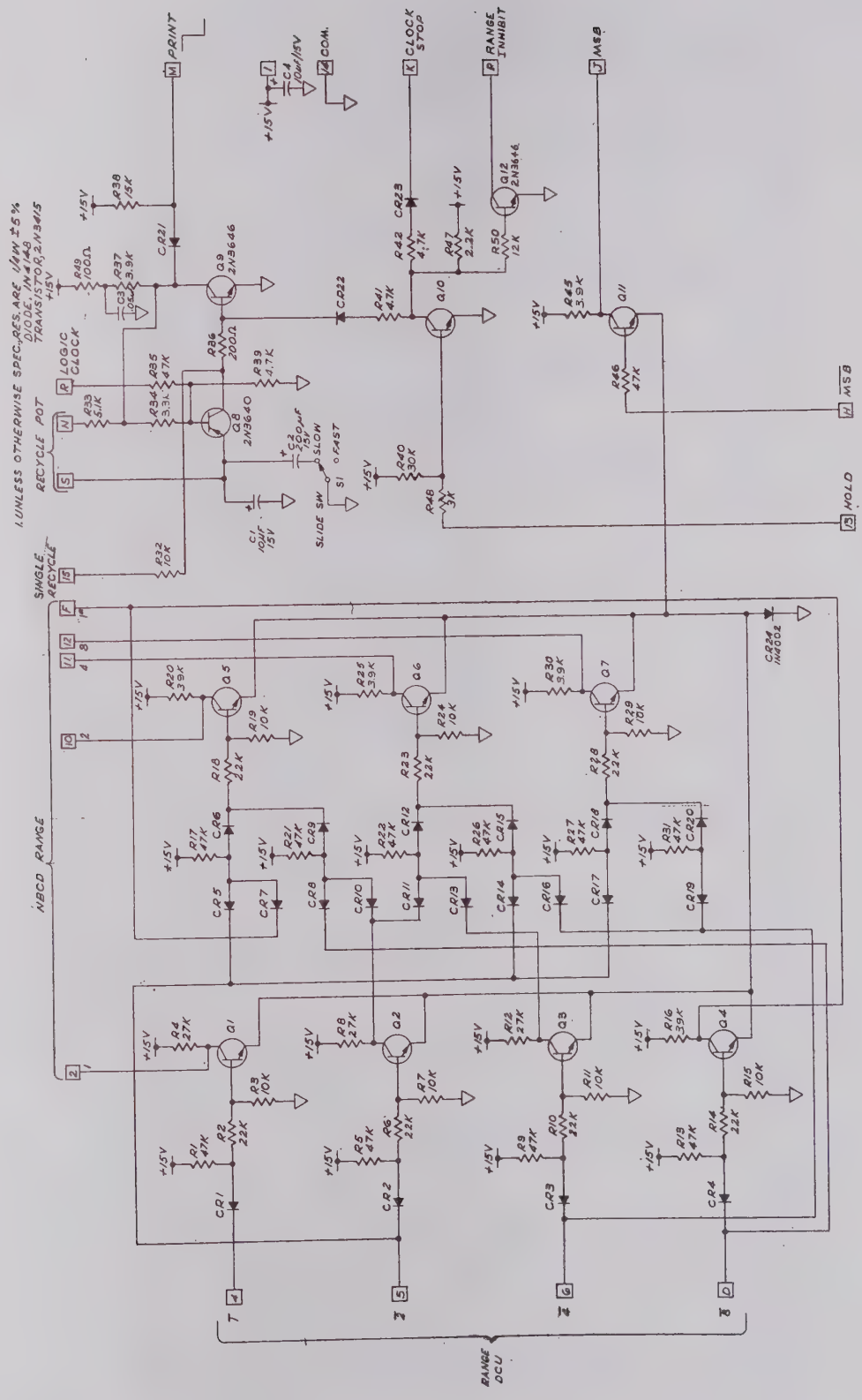


OPTION 01C &03C, HEX D CONVERTER SCHEMATIC
DWG. 33

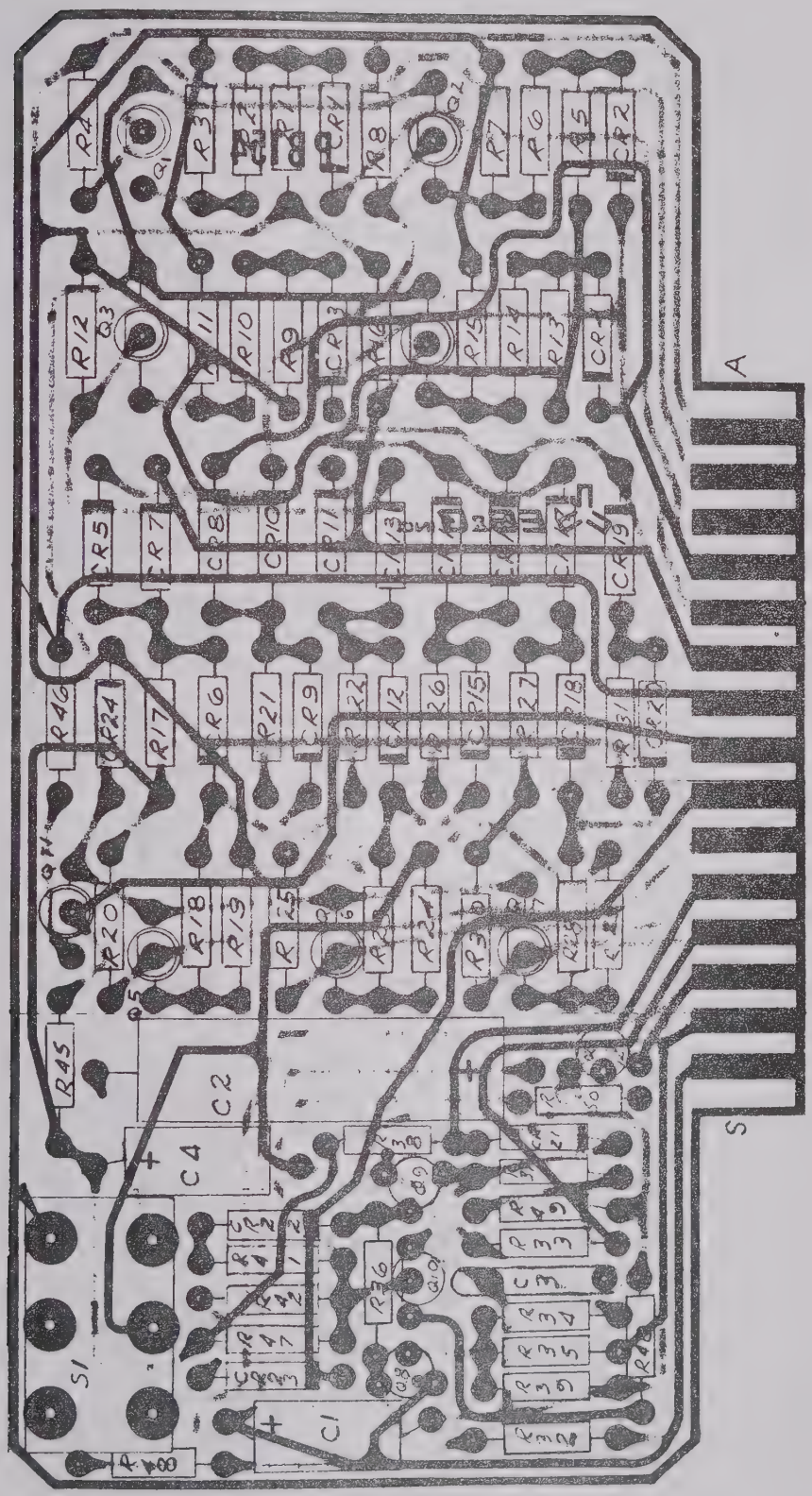
EG&G DWG. NO. PC-3172



EG&G DWG NO. PC-3172 OPTION 01C & 03C, HEX D CONVERTER ASSEMBLY
DWG. 34

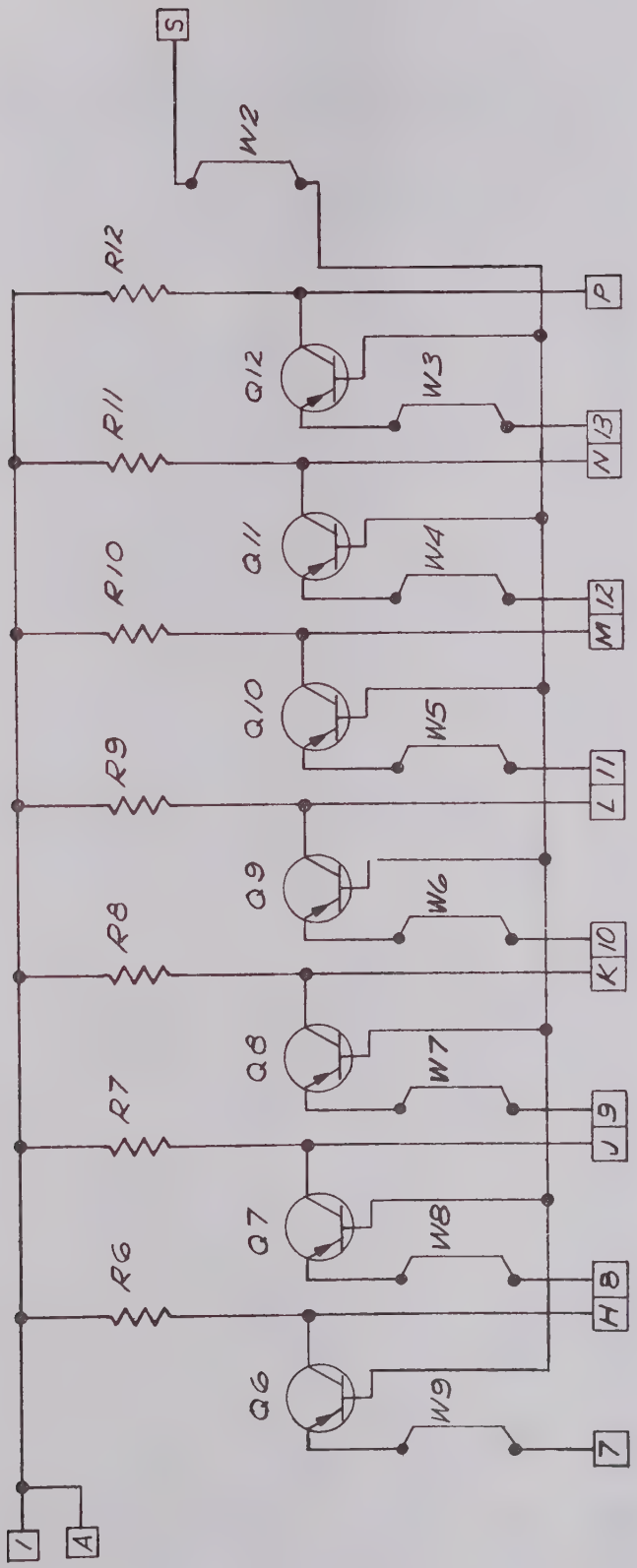


OPTION 01C, PRINT CONTROL AND RANGE DECODER SCHEM. EG&G DWG. NO. PD-3199
DWG. 35

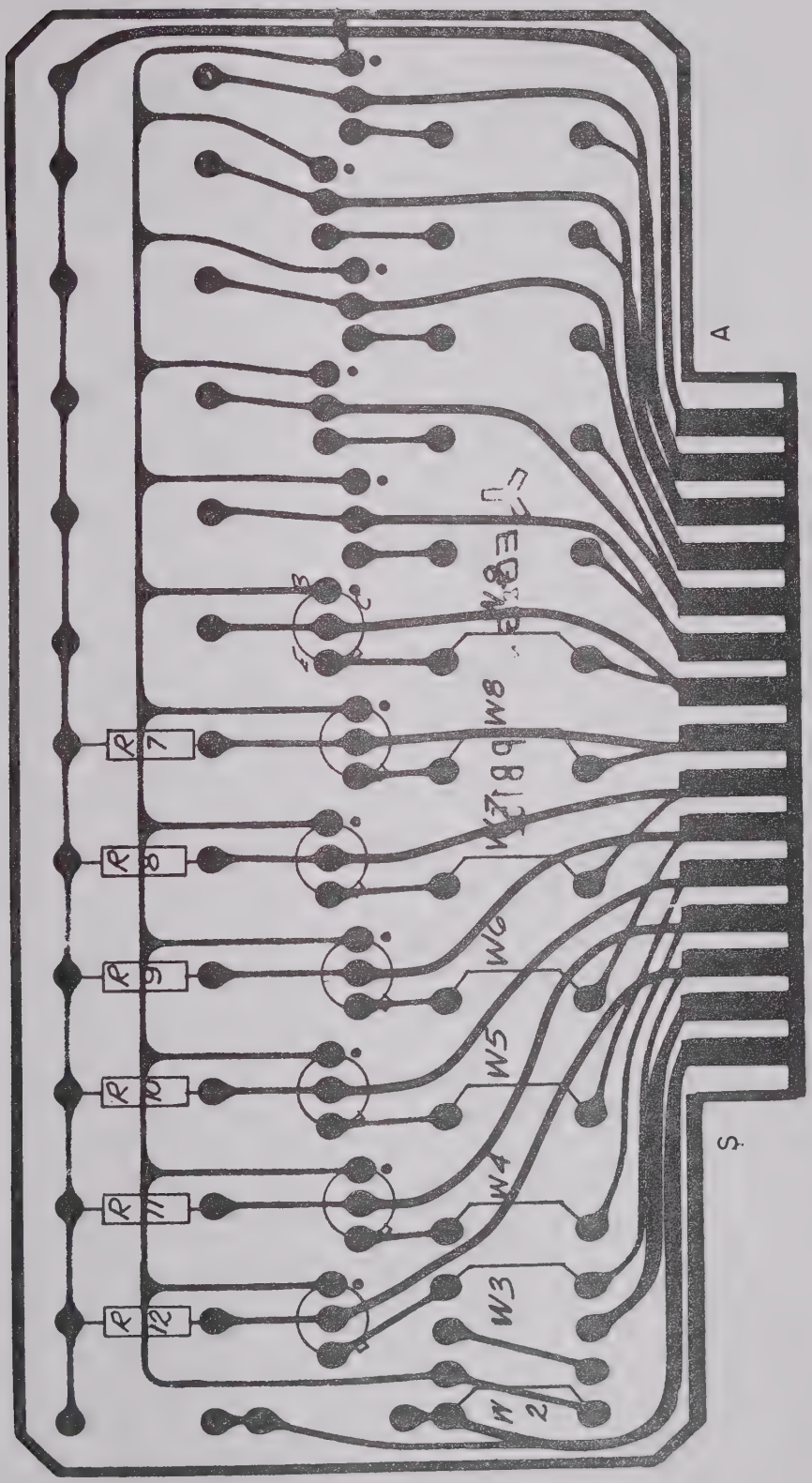


EG&G DWG. NO. PC-3199

OPTION 01C, PRINT CONTROL AND RANGE DECODER ASSEMBLY DWG. 36

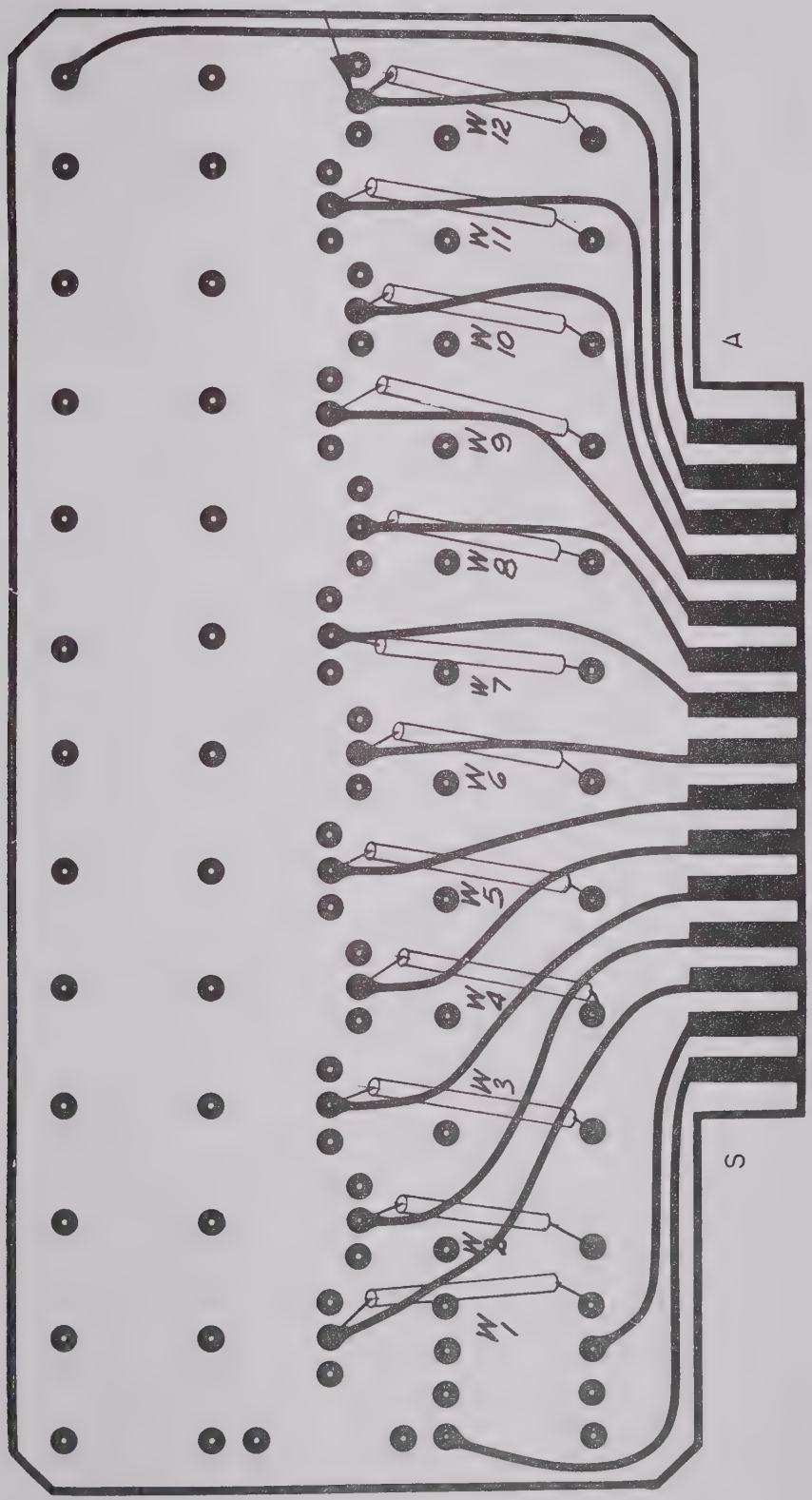


OPTION 01C & 03C, RANGE CONVERTER SCHEMATIC EG&G DWG. NO. PC-3171
DWG. 37



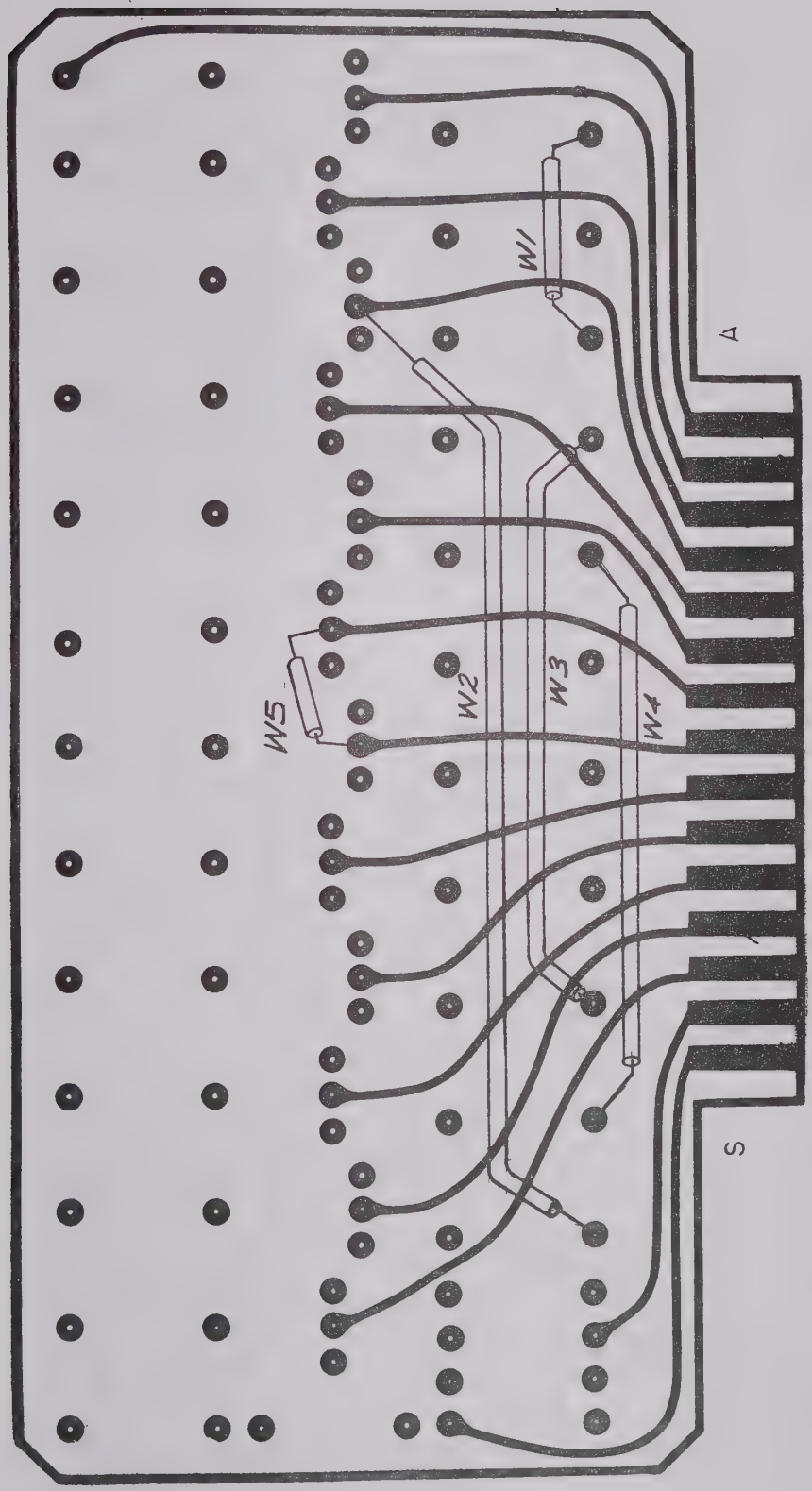
EG&G DWG NO. PC-3171

OPTION 01C & 03C, RANGE CONVERTER ASSEMBLY
DWG. 38



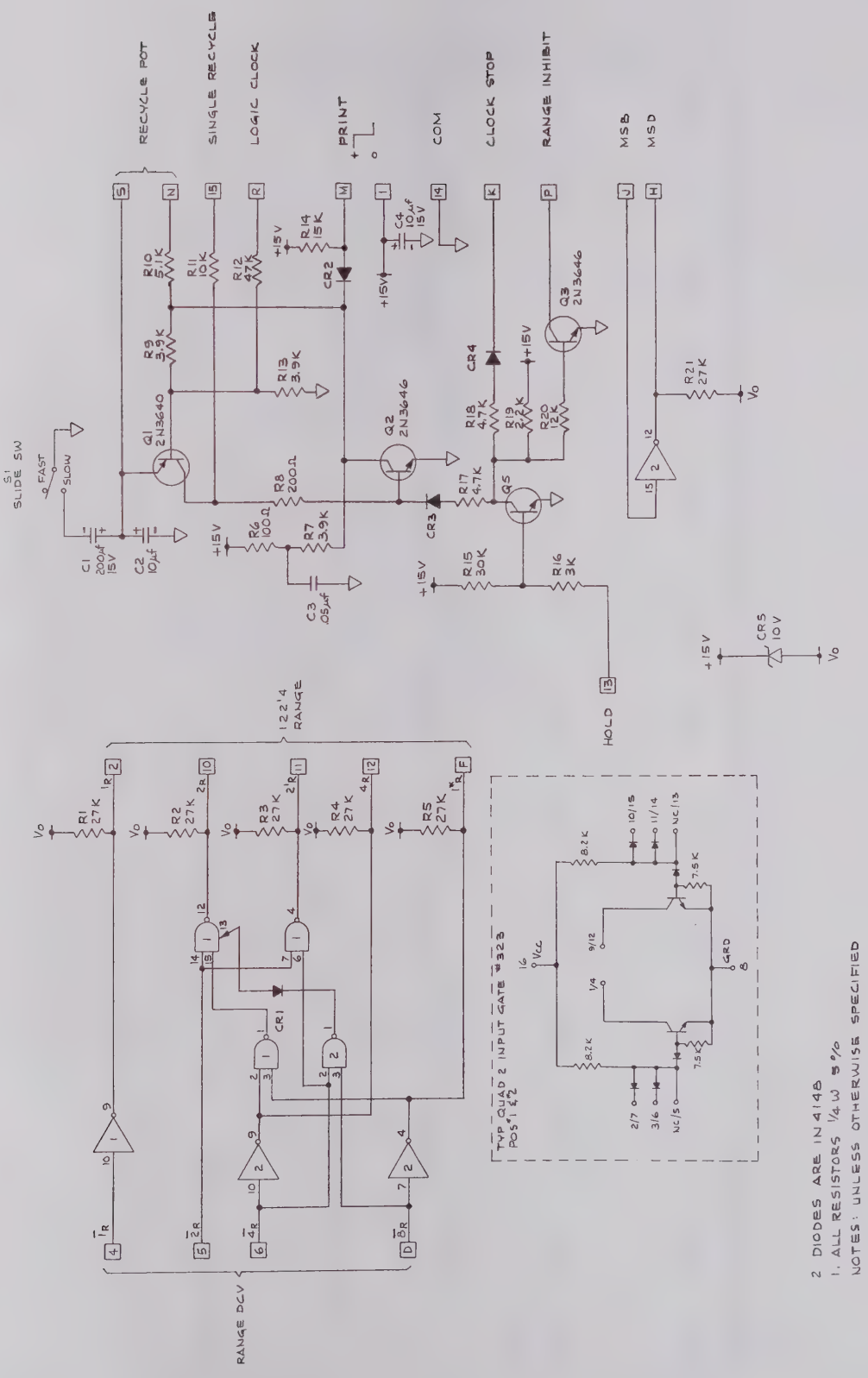
EG&G DWG. NO. PC-3174

OPTION 02A, HEX D JUMPER CARD
DWG. 39

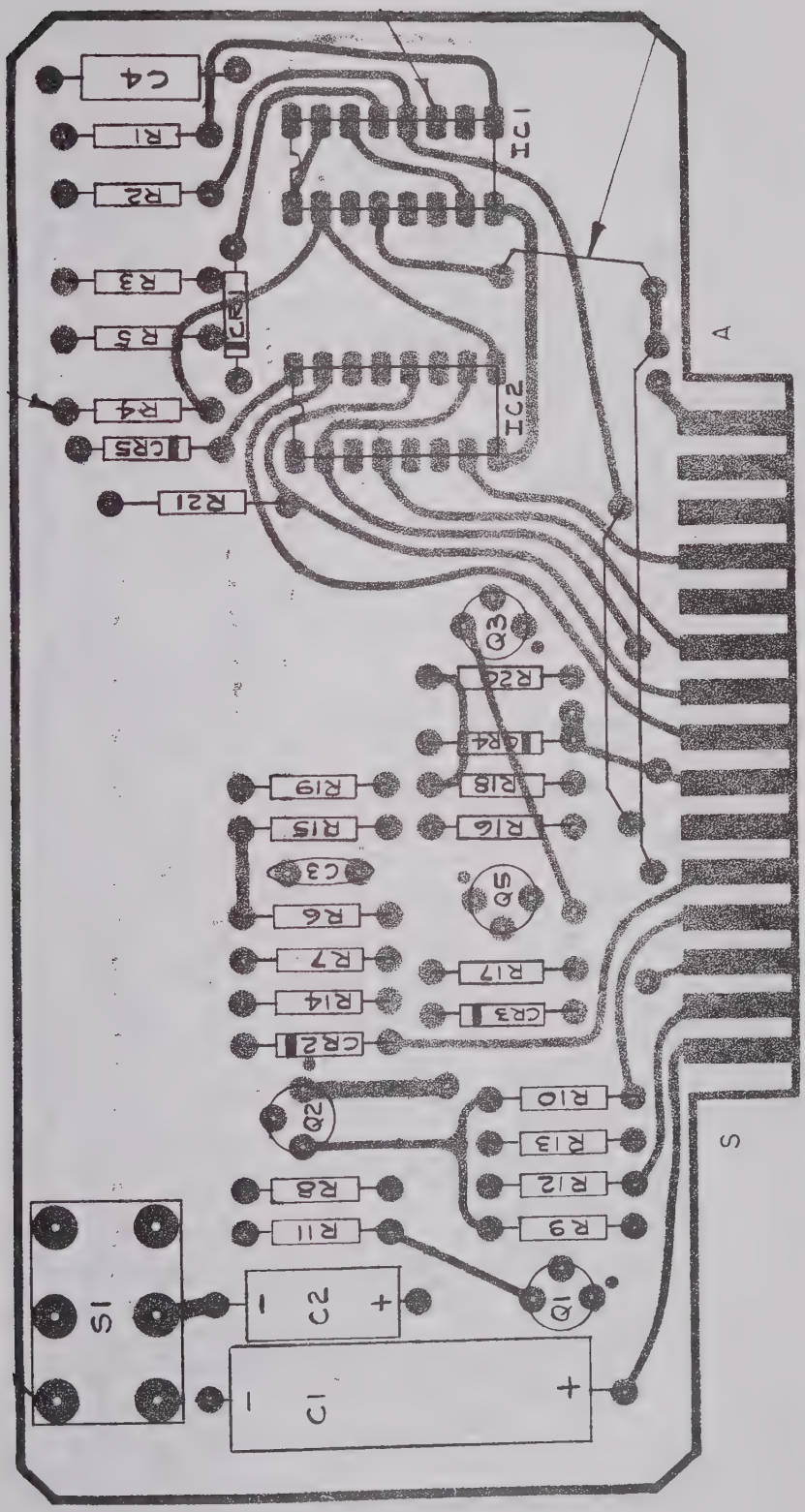


EG&G DWG. NO. PC-3173

OPTION 02A, RANGE JUMPER CARD
DWG. 40

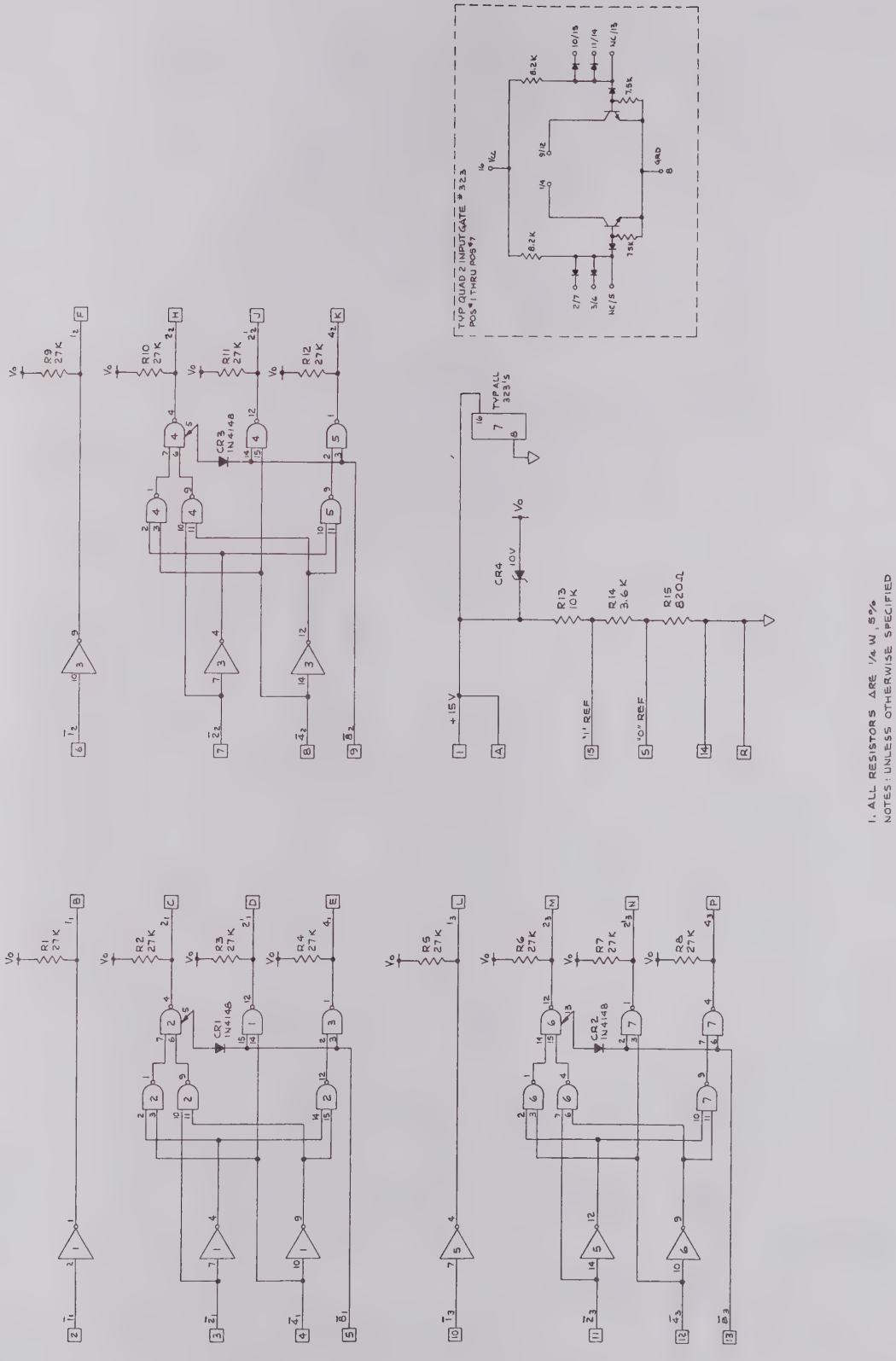


OPTION 03A, PRINT CONTROL AND RANGE DECODER SCHEM. EG&G DWG. NO. PD-3162 DWG. 41



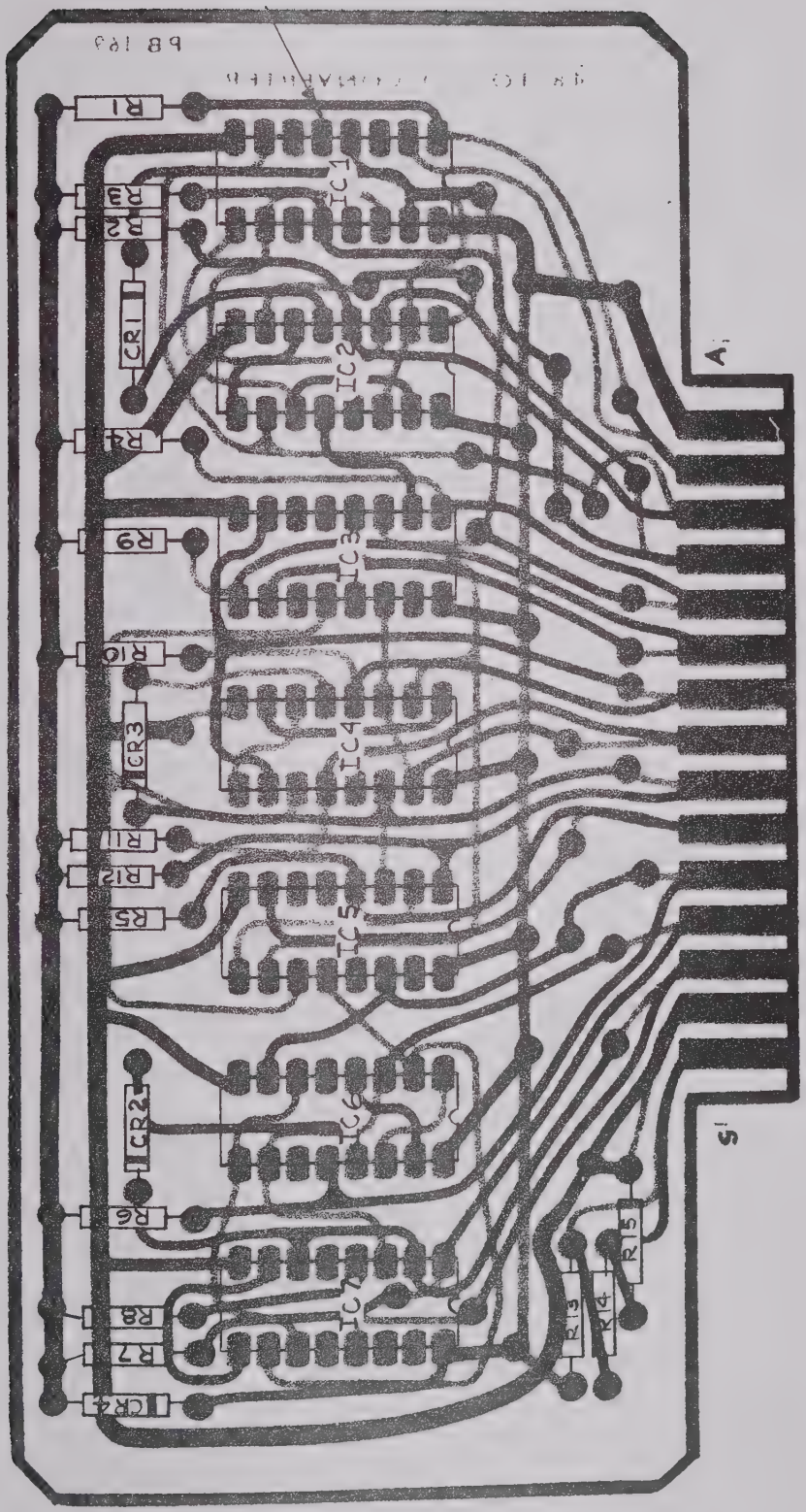
EG&G DWG. NO. PC-3162

OPTION 03A, PRINT CONTROL AND RANGE DECODER ASSEMBLY DWG. 42

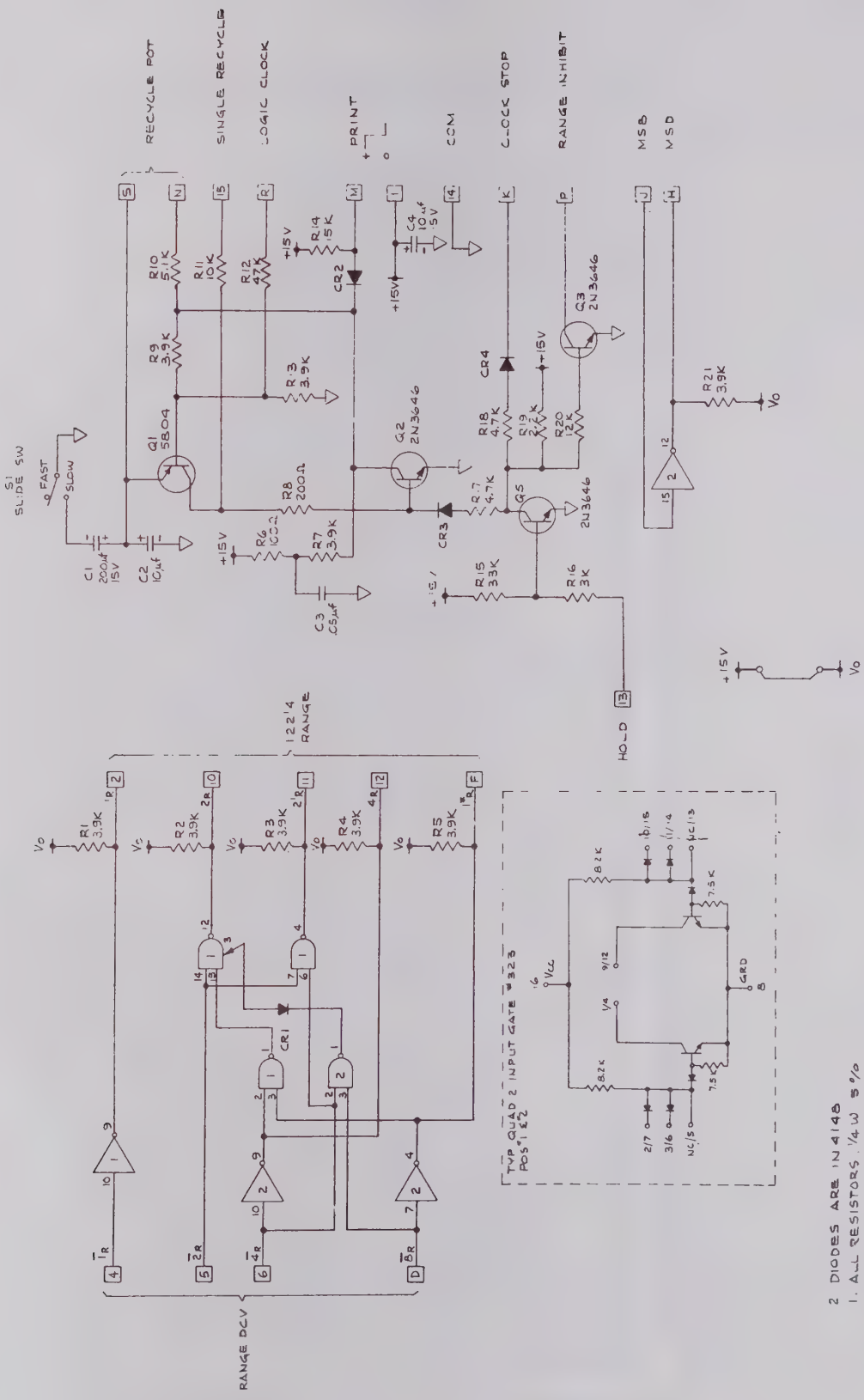


OPTION 03A, 1248 TO 122'4 CONVERTER SCHEMATIC
DWG. 43

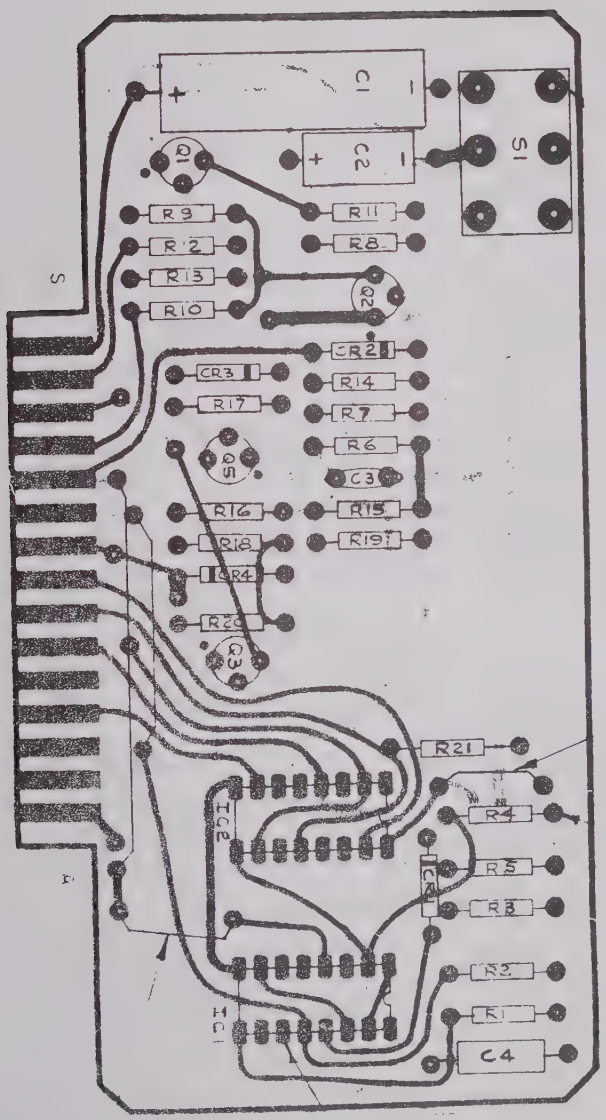
EG&G DWG. NO. PD-3158



EG&G DWG. NO. PC-3158 OPTION 03A, 1248 TO 122'4 CONVERTER ASSEMBLY DWG. 44



OPTION 03C, PRINT CONTROL AND RANGE DECODER SCHEM. EG&G DWG. NO. PD-3176 DWG. 45



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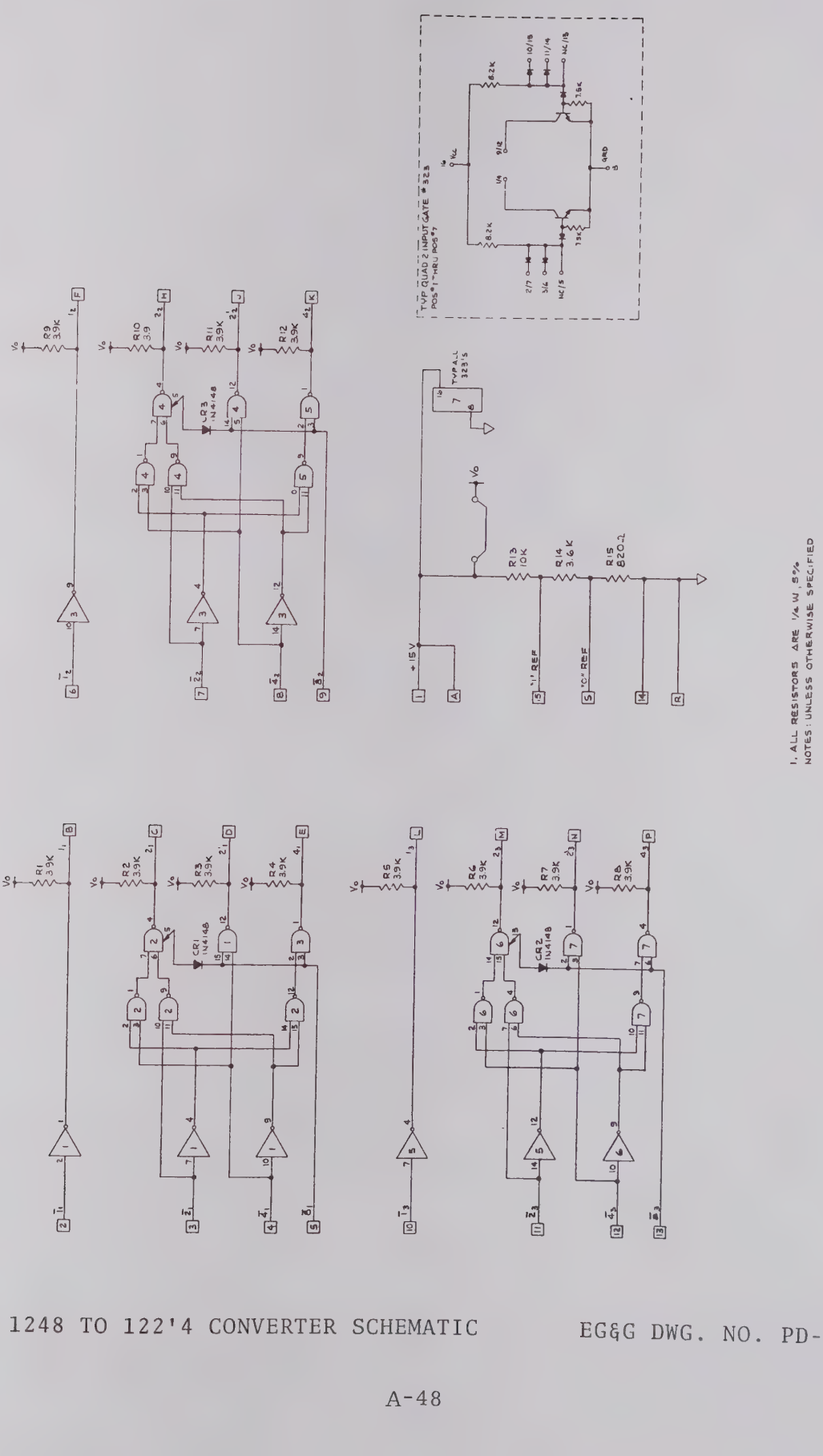
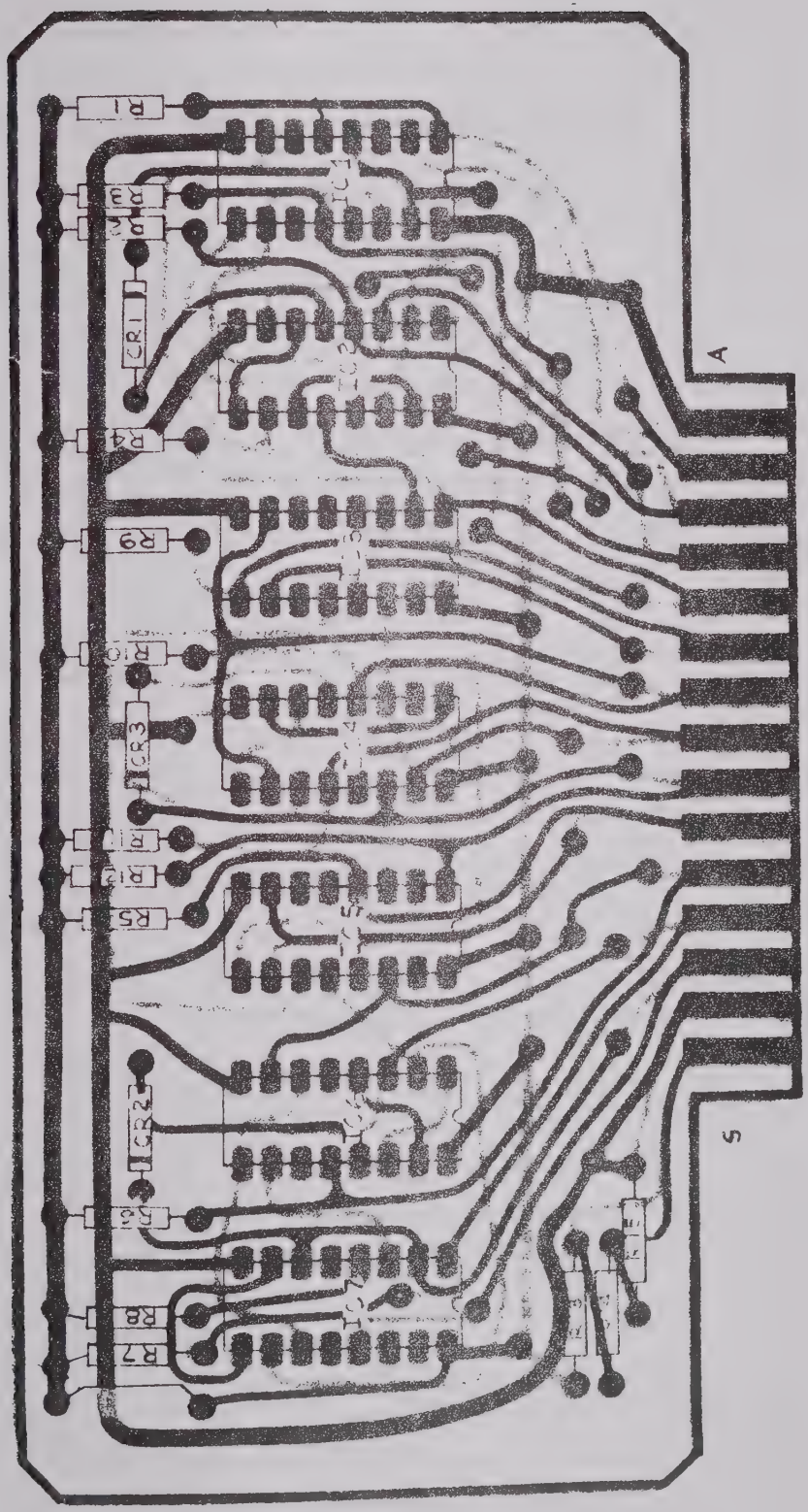


OPTION 03C, 1248 TO 122'4 CONVERTER SCHEMATIC
DWG. 47

EG&G DWG. NO. PD-3177



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APPENDIX B

SYMBOLS AND ABBREVIATIONS

ADC	Analog-to-Digital Converter
AUTO	Automatic
a.c.	alternating current
amp (a)	ampere
BCD	Binary Coded Decimal
BUG	Dual In-Line Integrated Circuit
CCW	Counterclockwise
CW	Clockwise
CMR	Common Mode Rejection
DAC	Digital-to-Analog Converter
DCU	Decimal Counting Unit
DEC	Decrease
DTL	Diode-Transistor Logic
db	decibel
fempto (f)	10^{15}
femptoamp (fa)	10^{15} ampere
F/F	Flip-Flop
F-R DCU	Forward-Reverse Decimal Counting Unit
f.s.	full scale
Giga (G)	10^{9}
Gigaohm (GΩ)	10^{9} ohms
Hz	Hertz (cycles per second)
IGFET	Insulated Gate Field Effect Transistor
INC	Increase
Kilo (K)	10^{3}
KHz	10^{3} Hertz (10^{3} cycles per second)
KΩ	10^{3} ohms
LSD	Least Significant Digit

MAN	Manual
MHz	10^6 Hertz (10^6 cycles per second)
MSI	Medium Scale Integration
MSD	Most Significant Digit
Mega (M)	10^6
MΩ	10^6 ohms
milli (m)	10^3
Millisecond (ms)	10^3 second
millivolt (mv)	10^3 volt
milliamp (ma)	10^3 ampere
micro (μ)	10^6
microsecond (μs)	10^6 second
microvolt (μv)	10^6 volt
microamp (μa)	10^6 ampere
nano (n)	10^9
nanosecond (ns)	10^9 second
nanoamperes (na)	10^9 ampere
NBCD	Natural Binary Coded Decimal (1248)
NMR	Normal Mode Rejection
O.R.	Over Range
O.S.	One Shot
opamp	operational amplifier
pico (p)	10^{12}
picoamp (pa)	10^{12} amperes
pot	potentiometer
P.C.	Printed Circuit
REM	Remote
RMS	Root-Mean-Square
sec (s)	second

SYMBOLS AND ABBREVIATIONS (cont'd.)

Tera (T)	10^{12}
Teraohm (TΩ)	10^{12} ohm
v	volt
w	watt
^{o}C	degrees centigrade
$\simeq$	approximately equals
<	less than, algebraic value (ex. < -12 would mean -13, -14, etc.)
>	greater than, algebraic value (ex. > -12 would mean -11, -10, etc.)
Σ_j	Summing Junction
Ω	Ohm
% f.s.	percent of full scale
% r.	percent of rading

BLOCK DIAGRAM SYMBOLS

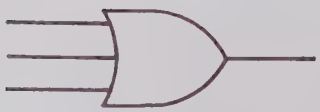
reed relay

high-megohm resistor ($> 10^7$ Ω)

pushbutton switch (normally open)

pushbutton switch (normally closed)

AND gate

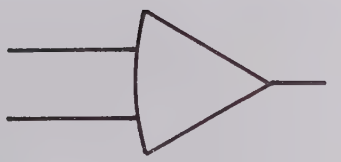


OR gate

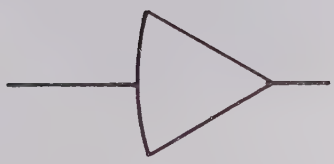
inversion

screwdriver adjustment

a.c. coupled input (capacitor)



differential operational amplifier



single-ended inverting operational amplifier

EG&G
LABORATORY PRODUCTS DIVISION

DATA SHEET 930A
June 1968

MODEL ME-930A
DIGITAL PICOAMMETER

MODEL ME-930A

The Model ME-930A is a full digital picoammeter with automatic range changing capability and automatic polarity selection.

The unit features all silicon solid state design, including a low level MOS FET input stage, remote function control and optional printer drive, digital readout of level and range.

As a standard with all EG&G picoammeters, the 930A has the capability for rapid, accurate calibration without calibration charts, measurement of resistors, etc.

This instrument has application in:

- Semiconductor leakage measurements.
- Photomultiplier measurements.
- Vacuum monitoring and control.
- Chromatography.
- Capacitor leakage systems.
- Component performance evaluation.
- Chemical processing.
- Photodensitometry.
- General laboratory.
- Mass spectrometry systems.

RANGE — 10^{-11} amps through 10^{-2} amps full scale in 10 decade steps.

RANGE DISPLAY — The range is displayed on front panel by neon glowtubes. A digital output is provided for remote monitoring of range.

DATA DISPLAY — Three full digits plus overrange is provided to give a maximum full scale data display of 1.999 on front panel by neon glowtubes. Digital output is 1248 format. (Option 01)

RESPONSE TIME

Range	Analog Output 10% to 90%	Digital Output to Within .2% of Final Value
10^{-11}	120 ms	840 ms
10^{-10}	15 ms	210 ms
10^{-9}	3 ms	200 ms
10^{-8}	400 μs	200 ms
10^{-7}	270 μs	200 ms
10^{-6}	80 μs	200 ms
10^{-5} to 10^{-2}	60 μs	200 ms

ACCURACY

10^{-2} amps to 10^{-6} amps	± .08% of reading ± 1 count
10^{-7} amps	± .25% of reading ± 1 count
10^{-8} amps	± .4 % of reading ± 1 count
10^{-9} amps	± .6 % of reading ± 1 count
10^{-10} amps	± .75% of reading ± 1 count
10^{-11} amps	± .95% of reading ± 1 count

The conditions under which these specifications are met:

Temperature	25° C ± 1° C
Relative Humidity	0–50%
Line Voltage	105–125 VAC, 60 Hz ± 5 Hz

Accuracy does not include effects of zero drift, self-input current, or temperature coefficient of feedback resistors.

TEMPERATURE COEFFICIENT

10^{-2} amps to 10^{-6} amps	100 PPM/° C
10^{-7} amps	300 PPM/° C
10^{-8} amps to 10^{-11} amps	1000 PPM/° C

POLARITY — Polarity selection is automatic. Polarity is displayed on front panel by a neon glowtube. A digital output is provided for remote monitoring of polarity.

PROGRAMMING — Programming is single point control to remote common line brought out with program lines. (Switch closure to remote common, or saturated NPN transistor.)

INPUT RESISTANCE — < .1 ohms on 10^{-2} amp range increasing by decades to < 5 megohms and 10^{-11} amp range.

INPUT ZERO DRIFT — Less than 200 μv/° C, and less than 1% of full scale on all ranges in 24 hours (after 10 minutes of operation).

SELF INPUT CURRENT — ± 10^{-13} maximum, ± 5 x 10^{-14} typical. Less than ± 5 x 10^{-15} amps/° C.

ANALOG OUTPUT — 0–10v @ 2 ma unipolar and bipolar for 100% overrange.

NOISE — Less than 0.2% RMS with maximum damping. Less than 0.7% RMS with minimum damping @ 10^{-12} amps.

OPTION 01 — Includes manual and automatic printer rate control from 5 lines per second to 100 seconds per line with H-P printer N39-562A, 1248 BCD output for range exponent and current
< +1v = "O" , > +5.5v = "1" .

OPTION 02 — 1248 N BCD on current, 1248 N BCD on range < +1v = "1" , > +5.5v = "O" .

OPTION 03 — 122'4 BCD on current.
122'4 BCD-2 < +1v = "O" , > +5.5v = "1" .
Option 03 includes manual and automatic printer rate control from 10 lines per second to 100 seconds per line.
Other options available upon request.

SIZE — 3-1/2" x 17" x 17". Standard bench-top with rack mount option.

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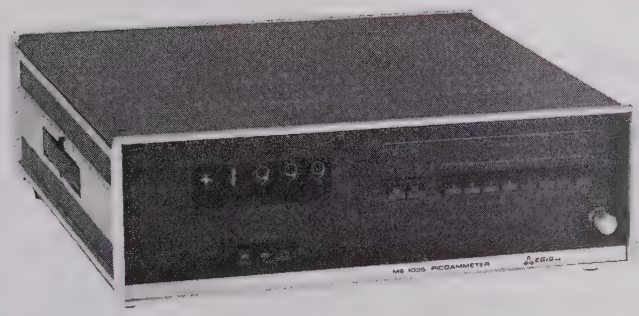
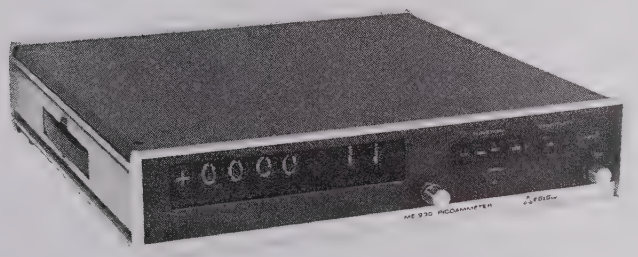
NEW EG&G PICOAMMETERS

A full line of low-level current measurement instruments

All EG&G Picoammeters include features others only talk about. Like the unique combination of precise accuracy and rapid, accurate calibration capability without resorting to calibration charts or resistor measurement. And, the all solid-state design, including a low level MOS FET input stage. What's more . . . you'll find an EG&G Picoammeter to meet *your* needs and *your* budget. That's because EG&G offers the most complete line of low level current measurement instruments available. From high precision units or automatic ranging units, both complete with digital readout, to general purpose, manually-operated bench top models.





HERE ARE THE SPECIFICS ON FOUR OF THE MOST POPULAR EG&G PICOAMMETERS.

Model ME-1035, Precision Picoammeter — for Standards or Calibration labs. Current measuring range of 10^{-5} amps to 10^{-12} amps with 10^{-15} amps resolution. All solid state design with MOS FET input, temperature controlled feedback resistors for added stability, pushbutton range control, adjustable summing point voltage and current offset monitor, pushbutton controls for rapid internal calibration requiring no external standards or sources. Digital readout. Price: $3,945.00

Model ME-930, Digital Picoammeter — for general lab work and automatic digital systems. Current measuring range of 10^{-11} amps through 10^{-2} amps full scale in 10 decade steps. A full digital picoammeter with automatic range changing capability and automatic polarity selection. All solid-state design with MOS FET input, remote function control and optional printer drive, digital readout of level and range. Price: $3,575.00

Model ME-920, Automatic Range Changing Picoammeter — for general laboratory use and production line testing. Current measuring range of 10^{-11} amps through 10^{-2} amps in 10 decade steps. An automatic ranging picoammeter with remote function capabilities. All solid-state design, with MOS FET input and automatic polarity indication. Price: $2,435.00

Model ME-705, General Purpose Picoammeter — for general laboratory use. Current measuring range of 3×10^{-13} amps through 10^{-2} amps in 22 steps (11 decades with X3 meter multiplier). A general purpose, manually operated bench-top picoammeter. All solid-state design, with MOS FET input stage. Price: $560.00

For more complete details on the more complete line of EG&G Picoammeters, contact your local EG&G Products Division representative. Or, write EG&G Inc., Laboratory Products Division, P.O. Box 755, Goleta, California 93017.

VISIT US DURING IEEE, Booth numbers 3B40-3B41.

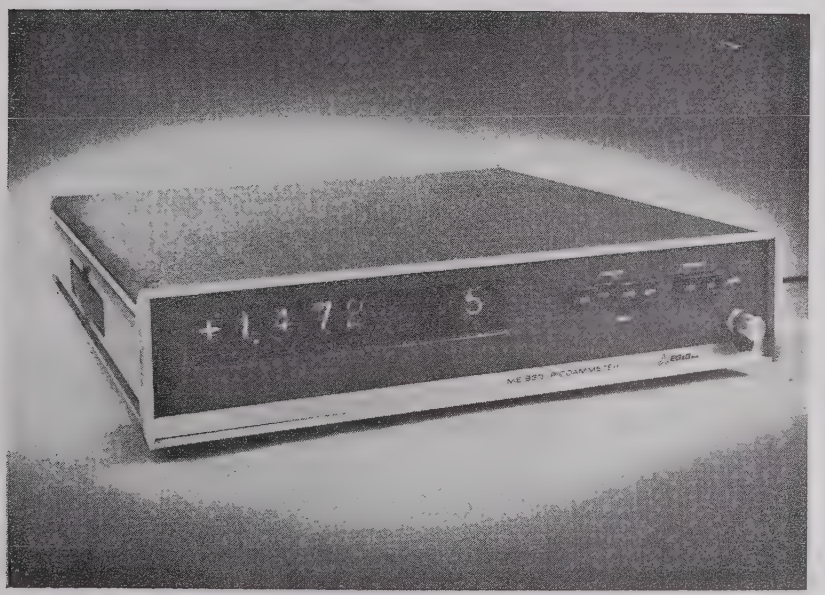
EG&G
LABORATORY PRODUCTS DIVISION

This advertisement will appear in the March, 1968 issue of Instruments and Control Systems. 30-58

Evaluating Picoammeter Accuracy and Convenience Factors

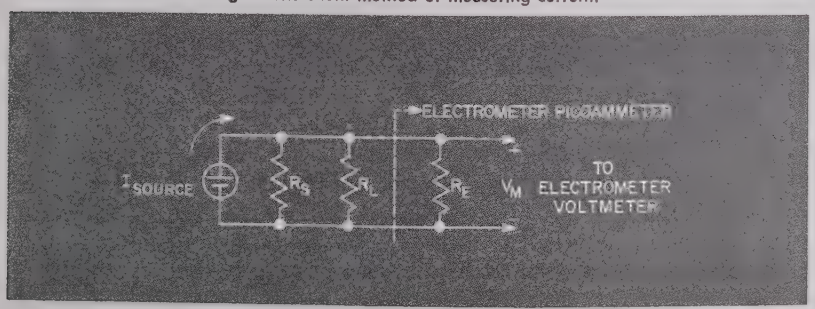
Now that digital, as well as analog, picoammeters are available, the user must choose between them to satisfy his particular application requirements.

BY LAWRENCE G. BRUNETTI*



Featuring automatic range-changing capability and automatic polarity selection and indication, the Model ME-930 Digital Picoammeter is a solid-state instrument that displays current readings in three digits plus 100% overrange. A 1-2-4-8 BCD output is also available. Full-scale current ranges extend from 10 mA to 10 pA, in 10 decade steps. Accuracy (excluding effects of zero drift and self-input current) is stated as ±0.08% of reading ± 1 count (1-μA to 10-mA ranges), and to ±0.95% of reading ± 1 count (10-pA range). Additional specifications include: input resistance, < 0.1 Ω (10-mA range) to < 5 mΩ (10-pA range); input zero drift, < 200 μV/°C and < 1% fs/24 h; self input current, ±100 fA max, ±50 fA typical; programming, via contact closures to common; and operating temperature, 25°C ± 5°C.

Fig. 1. The shunt method of measuring current.



Analog instruments that are capable of measuring picoampere-level currents (i.e., of the order of 10^{-12} ampere) are well known, and have been improved over a number of years to provide accurate, reliable measurements of minute currents. The recent development of the digital picoammeter—which exhibits significantly different features, due to the constraints imposed by the digital readout—now presents the test engineer with a choice not only among different models of the same *kind* of instrument, but between analog and digital instruments, as well. In addition to the differences among performance characteristics, there is a significant difference in price between analog and digital instruments, that must be weighed against performance in the selection of an instrument for a particular application.

Low-Level Current Measurement

Low-level currents are generally measured by one of two methods, that exhibit distinctly different input characteristics. The shunt method, shown in Fig. 1, employs an electrometer (a high-input-resistance voltmeter) to measure the voltage drop across a high value of resistance. In this case, the input, V_M, to the electrometer is

*Laboratory Products Division, EG&G

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$$V_M \approx I_S R_E \left[1 - \left(\frac{R_E}{R_L} + \frac{R_E}{R_S}\right)\right] \quad (1)$$

where V_M = picoammeter input voltage
R_E = shunt dropping resistance (input resistance)
R_L = shunt leakage resistance
R_S = source resistance
I_S = source current
R_E/R_L represents the error due to leakage current
R_E/R_S represents the error due to source loading

This is an obvious extension of an elementary technique to the measurement of low-level currents. While it enjoys the advantage of simplicity, the principal disadvantage of the electometer picoammeter is its high input resistance, which is equal to the value of the shunt dropping resistor. High input resistance can impose an extreme limitation upon measurement time. For example, if R_E is 1 TΩ (a common value for an electrometer-tube input), and if the shunt capacitance is as little as 100 pF (a typical value for about 3 ft of coaxial cable), then the time constant, RC, will be $10^{12} \times 100 \times 10^{-12} = 100$ seconds, and a measurement to an accuracy of only 1% will require a measurement time of 500 seconds (more than 8 minutes).

Figure 2 shows the operational method of measuring low-level currents, in which the dropping resistor is connected as the feedback resistor of an operational amplifier. In this case, the operational amplifier output voltage, V_o, will be

$$V_o \approx I_S R_F \left[1 - \frac{1}{A}\left(\frac{R_F}{R_L} + \frac{R_F}{R_S} + 1\right)\right] \quad (2)$$

where I_S, R_S, and R_L are as defined in equation (1)
V_o = operational amplifier output voltage
R_F = amplifier feedback (dropping) resistor [Note: R_F is not necessarily the same as R_E in equation (1); in general, $R_E >> R_F$]
$-A$ = amplifier open-loop gain
leakage and source-loading error terms are reduced by the value of open-loop gain

The effective picoammeter input resistance, R_{in}, in this case will be

$$R_{in} \sim \frac{R_F}{A} \quad (3)$$

Ignoring second-order or side effects, this operational picoammeter reduces the input resistance by a factor that is equal to the open-loop gain of the amplifier. The effects of this lower input resistance include:

- Reduced loading of the source (where accuracy is practically independent of source voltage, and the summing junction becomes the principal limiting factor);
- Reduced requirements for extremely high values of input leakage resistance; and
- Faster response time for a given value of shunt input capacitance.

Source loading becomes significant when the resistance of the current source approaches the value of the picoammeter's input resistance. That is, the Thevenin equivalent voltage of the current source must be large compared with the value of input voltage required to produce full-scale output. In an electrometer instrument, this value of input voltage is equal to the full-scale voltage drop across the shunt input resistor, while in an operational configuration, it is reduced by the value of amplifier open-loop gain. Notice, however, that unless the source resistance, R_S, is very much greater than the feedback resistance, R_F, it will reduce the feedback by divider action, thereby reducing the stability of the amplifier.

A further advantage of the operational configuration is its ease of calibration. As shown in Fig. 3, its feedback can be taken from a simple low-impedance voltage divider across the output, so that changes in value of the high-resistance feedback resistor can be compensated

Fig. 3. The use of variable feedback in the operational configuration for the measurement of current.

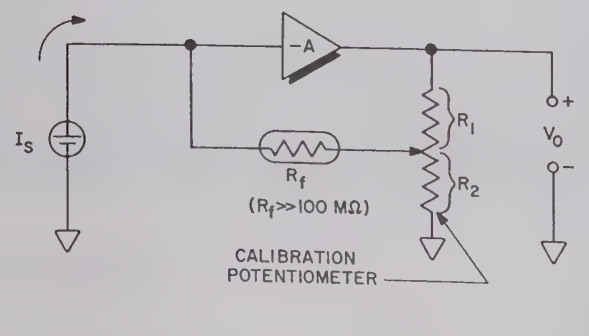
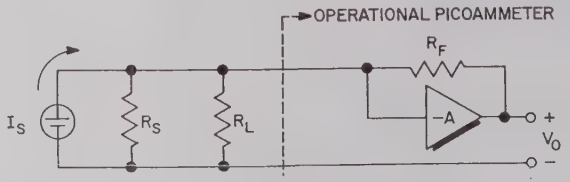


Fig. 2. The operational method of measuring current.



readily. For this circuit, if the amplifier gain, A, is very large

$$-\frac{V_o}{I_S} = R_f \left[\frac{R_1}{R_2} + 1\right] + R_1 \quad (4)$$

where V_o and I_S are as defined previously [equations (1) and (2)]

R_1 and R_2 are a calibration potentiometer

R_f is the feedback resistor

The Digital Picoammeter

The measurement of low-level direct currents to a resolution of less than one picoampere by means of manually operated analog instruments requires skill in measurement techniques, as well as interpretation by a trained operator, or an engineer or scientist. The digital picoammeter has evolved to facilitate the routine measurement of low-level currents, where greater amounts of higher-accuracy data are required.

The automatic digital instrument must be more than a digitized version of earlier analog instruments. Its digital readout requires accurate range correlation, negligible zero drift (in all ranges), and a high degree of normal-mode noise rejection. In addition, it must switch high-resistance feedback elements in a transient-free manner, to provide automatic range changing at rates that are commensurate with its response speed. These constraints arise from the inherent nature of a digital display, which demands range correlation to the least-significant digit, stable input circuitry to eliminate "zero chasing" (hunting), and a workable compromise between response time and noise rejection. An automatic digital picoammeter that meets these requirements is shown on the title page of this article.

The readout of an analog meter movement is subject to interpretation, that often leads to a certain amount of accommodation, as well. Thus, the normal reaction in reading the indication of an analog picoammeter is to regard range-correlation errors of the order of 1% to 3% as minor (if they are not disregarded entirely), to accept frequent zero adjustments (even between ranges) as standard procedure, and to average out, mentally, the effects of noise on the meter indication. A digital display, on the other hand, has no built-in interpretation. It forces one to notice such discrepancies. This effect can be demonstrated dramatically by connecting a high-resolution DVM to the output of an analog picoammeter.

- *Range Correlation* may be defined as the degree of displayed consistency between any two adjacent ranges. In a digital instrument, range correlation error should be no greater than ± the least-significant digit.

- *Zero Drift* must be extremely low in an automatic instrument, if it is to provide reliable measurements. The insulated-gate field-effect transistor (IGFET) can provide performance superior to that of the electrometer tube—the use of which, for many years, was mandatory for extremely low-current, high-resistance applications. The zero-biased differential IGFET input stage can realize less than 1-millivolt-per-week drift—a value seldom attained by the electrometer tube.

- *Automatic Range Changing*, which is necessary in an automatic instrument, should be accomplished at as fast a rate as response time of the instrument will permit. The modern digital picoammeter is capable of sweeping through all of its ranges and providing a measurement result to rated resolution in less than 500 milliseconds.

- *Normal-Mode Noise Rejection* is also very important in an automatic picoammeter, since accurate, reliable measurements can be made only if the noise level is below the resolution required of the measurement. Noise rejection is often accomplished by means of filters (e.g., an active filter at the A-to-D-converter input, where it will not materially affect the time constant of the instrument), in conjunction with some form of bandwidth control to narrow the bandwidth as much as possible on the most sensitive ranges. Note, however, that narrowing the response bandwidth will, in general, cause a corresponding increase in the response time of the instrument.

Selection Criteria

The choice between an analog or a digital picoammeter is largely a matter of convenience, since an analog instrument *can* provide performance equal to that of its digital counterpart. However, the constraints imposed by a digital readout require careful design to minimize such disturbing influences as drift and noise, and to achieve an optimum compromise between response time and noise rejection. This is not *necessarily* true of an analog instrument.

Where response time is of little concern, the shunt method employing an electrometer is simple and relatively inexpensive. However, it does require a certain amount of technique expertise and interpretation to produce reliable measurements.

If response time must be minimized, the operational picoammeter—either analog or digital—is the only possible choice. Use of the operational configuration also requires much less of the operator in order to produce valid measurements.

However, if requirements upon the skill and knowledge of the operator must be minimized, or if convenience of operation is considered sufficiently important, then the most sophisticated instrument available—the automatic digital picoammeter—will be the best choice. K

See biography on back page.

Lawrence G. Brunetti *received the BSEE degree from the University of Nevada in 1959, and the MSEE degree from the University of California at Berkeley in 1964. During the period from 1959 to 1961, he was associated with the General Electric Company in Syracuse, N.Y. where, in the Defense Systems Dept., he was concerned with guidance system operations for Atlas and Titan I. He joined EG&G in Las Vegas, Nevada in 1961, and worked on circuit and instrument design for early phases of nuclear rocket development (Rover). Then, in 1964 he became a Custom Products Engineer with Beckman Instruments, Inc. in Richmond, Calif. Since 1965, Mr. Brunetti has been associated with EG&G Laboratory Products Division, Goleta, Calif., where he is currently Engineering Manager for Picoammeter Products and Systems, and Thermoluminescent Dosimeter Reader Systems.*

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